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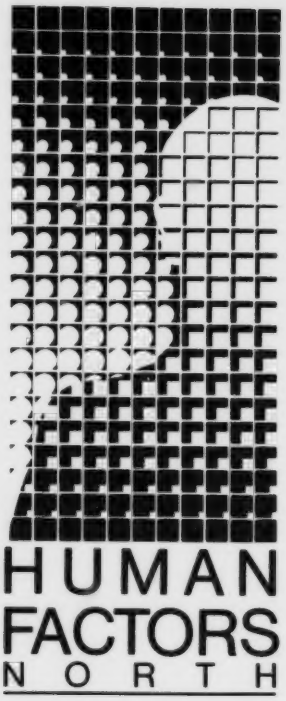

ARCTIC TASK ANALYSIS AND NAVIGABILITY STUDY

Prepared for

Transportation Development Centre

Transport Canada

D.J. Ostry, M.G. Lowings, D.C. Donderi

Human Factors North Inc.

Toronto, Ontario

March 1986

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17. Abstract

This report presents the findings of coordinated task analysis and navigability studies conducted aboard M.S. Tuuleland during fall 1984 and M.V. Canmar Kigoriak during fall 1984 and spring 1985. The objectives were the development of an understanding of the information requirements for Arctic navigation and the elaboration of scenarios for an Arctic shiphandling simulator that are based on actual operations or transits in Arctic waters. Several types of information necessary for simulator development are presented. This includes detailed descriptions of actual operations and of operator performance that are the basis for scenarios to be used for training on and validation of an Arctic shiphandling simulator; the information requirements for preparing scenarios to be used for training; a matrix of simulator scenarios that consists of a seasonal and geographic index of operations in different types of ice conditions; colour and luminance of the Arctic marine environment measured under actual operating conditions; data on the motion of a ship during ramming, backing and maintaining station in ice with engines running. Computer-generated diagrams of Arctic gaming areas are also provided. In addition, the report discusses sources of information for close tactical, tactical and strategic decision making; the use of remote sensors; and aids to night vision in Arctic navigation. Conclusions of these coordinated studies are presented as they relate to the development of an Arctic shiphandling simulator and to Arctic navigation technology.

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17. Résumé

Ce rapport donne les conclusions de l'analyse des tâches de pilotage faite en coordination avec les études sur la tenue en mer des navires, à l'automne de 1984 à bord du N.M. Thuleland et, à la même période ainsi qu'au printemps de 1985, à bord du Canmar Kigoriak. L'objet de cette étude a été de déterminer la nature des informations nécessaires à la navigation arctique et de déboucher sur l'élaboration de logiciels pour la simulation de la navigation dans l'Arctique, logiciels fondés sur la manoeuvre réelle de navires naviguant dans les hautes latitudes.

Il présente plusieurs types d'informations nécessaires à l'étude d'un tel simulateur, à savoir: descriptions détaillées des manoeuvres de pilotage et de l'exécution des tâches correspondantes, sur lesquelles asseoir les logiciels devant servir tant à la validation de la simulation qu'à la formation des utilisateurs futurs; données à prendre en compte dans l'élaboration des logiciels de formation; matrice des logiciels comportant un index des manoeuvres qui peuvent varier selon l'emplacement géographique, la saison et les conditions glacielles; intensités des coleurs et de la lumière dans les divers milieux arctiques, mesurées in situ; données sur les mouvements du navire durant les marches alternées et pour le maintien en position dans les glaces, moteurs en marche. Il présente des visuels de simulation infographiques représentant des régions arctiques et aborde, en outre, les sources d'information à consulter pour les prises de décisions tactiques approchées, tactiques et stratégiques ainsi que pour la télédétection et les aides à la navigation nocturne dans les eaux arctiques.

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SUMMARY

This report presents the findings of coordinated task analysis and navigability studies conducted aboard M.S. Thuleland during fall 1984 and M.V. Canmar Kigoriak during fall 1984 and spring 1985. The objectives were the development of an understanding of the information requirements for Arctic navigation and the elaboration of scenarios for an Arctic shiphandling simulator that are based on actual operations or transits in Arctic waters.

Several types of information necessary for simulator development are presented. This includes detailed descriptions of actual operations and of operator performance that are the basis for scenarios to be used for training on and validation of an Arctic shiphandling simulator; the information requirements for preparing scenarios to be used for training; a matrix of simulator scenarios that consists of a seasonal and geographic index of operations in different types of ice conditions; colour and luminance of the Arctic marine environment measured under actual operating conditions; data on the motion of a ship during ramming, backing and maintaining station in ice with engines running. Computer-generated diagrams of Arctic gaming areas are also provided. In addition, the report discusses sources of information for close tactical, tactical and strategic decision making, the use of remote sensors, and aids to night vision in Arctic navigation.

The main conclusions of these coordinated studies as they relate to the development of an Arctic shiphandling simulator are that (1) simulator validation must be based on comprehensive accounts of actual operations and quantitative measures of piloting performance in the environments to be simulated; (2) the gaming area for simulator training scenarios should be based on actual SAR imagery; and, (3) more data on bridge motions should be collected to properly determine the need for a motion platform.

The database of navigability and operator performance information is far from complete. This information is needed not only for purposes of simulation, but also for the realistic and accurate assessment of operator workload, risk and Arctic ship safety. Navigability and operator performance data also provide a quantitative basis for decisions regarding bridge design, manning and regulations development.

SOMMAIRE

Ce rapport donne les conclusions de l'analyse des tâches de pilotage faite en coordination avec les études sur la tenue en mer des navires, à l'automne de 1984 à bord du N.M. Thuleland et, à la même période ainsi qu'au printemps de 1985, à bord du Canmar Kigoriak. L'objet de cette étude a été de déterminer la nature des informations nécessaires à la navigation arctique, et de déboucher sur l'élaboration de logiciels pour la simulation de la navigation dans l'Arctique, logiciels fondés sur la manoeuvre réelle de navires naviguant dans les hautes latitudes.

Il présente plusieurs types d'information nécessaires à l'étude d'un tel simulateur, à savoir : descriptions détaillées des manoeuvres de pilotage et de l'exécution des tâches correspondantes, sur lesquelles asseoir les logiciels devant servir tant à la validation de la simulation qu'à la formation des utilisateurs futurs; données à prendre en compte dans l'élaboration des logiciels de formation; matrice des logiciels comportant un index des manoeuvres qui peuvent varier selon l'emplacement géographique, la saison et les conditions glacielles; intensités des couleurs et de la lumière dans les divers milieux durant les marches alternées et pour le maintien en position dans les glaces, moteurs en marche. Il présente des visuels de simulation infographiques représentant des régions arctiques et aborde, en outre, les sources d'information à consulter pour les prises de décisions tactiques approchées, tactiques et stratégiques, ainsi que pour la télédétection et les aides à la navigation nocturne dans les eaux arctiques.

Les grandes conclusions de l'ensemble des études faites relativement à la mise au point d'un simulateur de navigation dans l'Arctique sont les suivantes : 1) pour un réalisme efficace, les logiciels de simulation doivent être fondés sur des descriptions détaillées de manoeuvres réelles et sur des caractérisations chiffrées des performances de pilotage dans l'environnement que l'on cherche à reconstituer; 2) le visuel de simulation doit être fondé sur une imagerie obtenue par un radar à antenne synthétique et 3) nécessité d'une banque de données plus abondante sur les mouvements ressentis sur la passerelle afin de déterminer avec précision la nécessité d'une plate-forme mobile sur vérins.

La base de données concernant les performances de pilotage et la tenue en mer est loin d'être complète; elle mériterait toutefois de l'être afin de pouvoir non seulement valider les logiciels de simulation, mais aussi faire une évaluation réaliste et précise de certains facteurs comme la charge de travail imposée à l'opérateur, les risques encourus et la sécurité. Cette base de données permettrait en outre de prendre certaines autres décisions vitales, concernant l'aménagement de la passerelle, les effectifs à prévoir et la mise au point des procédures à suivre.

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ARCTIC TASK ANALYSIS AND NAVIGABILITY STUDY

D.J. Ostry, M.G. Lowings, D.C. Donderi

Human Factors North Inc.

1. INTRODUCTION

Transportation Development Centre (TDC) and the Canadian Coast Guard have sponsored a number of studies related to the development of an Arctic shiphandling simulator. Some of these studies have investigated the equations which characterize ships' motion in ice, while others have dealt with the human engineering aspects of Arctic navigation and with ergonomic questions related to the visual and motion requirements for a simulator.

The present work is an integrated study of ships' operations in ice and operator control actions on the bridge. It has been made possible by the simultaneous collection of navigability and operator performance data. This approach was developed by Dr. R.M. Heron of TDC. Coordinated information gathering of this sort provides the data needed for the development of ship simulator scenarios and an understanding of the relationships between operator performance and Arctic ship safety.

The development of an Arctic ship simulator is a complex task that requires expert knowledge of Arctic navigation, ergonomics and ship simulation. In this report we combine ergonomic, navigability, and ice-related knowledge to develop a matrix of Arctic piloting scenarios. The matrix can be used for the purposes of simulator training and research. It also identifies requirements for future collection of navigability and operator performance data. Sixteen detailed scenarios are provided; these were developed from data collected aboard the M.V. Canmar Kigoriak and the M.S. Thuleland in the fall of 1984 and spring of 1985.

The data collected on these voyages add to the Arctic task analysis data base. The data base includes data from voyages in the spring and fall of 1983 aboard the M.V. Arctic. The stochastic properties of the task analysis data set are reported in Donderi and Ostry (1986). These data also add to the navigability data base that Coast Guard Northern has been developing since 1983. Transportation Development Centre has also contributed to the establishment of this data base.

This report also addresses specific questions proposed by TDC concerning sources of information for close tactical, tactical and strategic decision making; the use of remote sensors; and aids to night vision in Arctic navigation. In addition, Munsell colour samples, based on shipboard photometric recordings, are provided to show characteristic colours and luminances of the Arctic ice, sea, and sky. Some examples of the spectral characteristics of vibration on the bridge of the Kigoriak are also presented.

1.1 Organization of the Report

The report is organized in the following manner. Section 2 presents the matrix of Arctic piloting scenarios and a description of the details of scenario development for both the eastern and western Arctic. The scenarios are based on task analysis and navigability data collected on the M.S. Thuleland in September 1984 and the M.V. Canmar Kigoriak in October 1984 and June 1985. The scenarios incorporate a description of the actual piloting and communications which took place. Section 3 presents the main findings of the task analyses carried out in coordination with these scenarios. An examination of the stochastic structure of these events is found in Donderi and Ostry (1986). Section 4 presents the main conclusions of the report.

The report contains a number of appendices which supplement the primary objectives of this report and provide information pertinent to simulation. Appendix A provides encounter descriptions and computer-generated diagrams of the Arctic operations or transits described in Section 2. Appendix B provides a detailed listing of all entries in the matrix of piloting scenarios which can be identified to date, and the areas of Arctic operations to which they apply. Appendix C provides the findings of the computerized task analysis carried out in spring 1985, including stochastic modeling of the computer-collected data set. Appendix D describes, in terms of human operator performance, the information available from visual observation, ships' radar and SAR. The distribution of the use of radar, night vision aids and binoculars aboard both the Kigoriak and Thuleland is also described. Appendix E focuses on the requirements for night vision in the Arctic; suggestions for Arctic night lighting are also presented. The effects on luminance and visual contrast of the image intensifier aboard the Thuleland are described quantitatively. Appendix F supplements the colour and luminance data presented elsewhere in this report by providing normative colour samples of the Arctic sea, sky and ice based on photometric readings obtained on the Kigoriak and Thuleland. Appendix G gives a preliminary analysis of the motion characteristics of the bridge of the Kigoriak. A quantitative assessment of the motion spectrum on the bridge is needed to determine the role of motion cues to the operator in ship piloting performance. This will help determine the kinds of motion that should be incorporated in an Arctic ship simulator to produce a valid simulation.

2. CATEGORIES AND DESCRIPTIONS OF SIMULATOR SCENARIOS

2.1 Introduction

This section presents a matrix of Arctic piloting scenarios that can used for purposes of simulator training and research. We indicate as well the kinds of information which must be included in scenarios in order to use them in the development, operation and validation of a simulator. The preparation of shiphanding scenarios is also described.

Our work is based on coordinated collection of navigability and operator performance data in the eastern and western Arctic. This approach was developed by Dr. R.M. Heron of TDC. In the case of eastern Arctic waters, the detailed scenarios are related to critical navigation incidents, involving encounters between the ship and hazardous ice or other navigation hazards. For western Arctic waters, the scenarios follow from accounts of actual operations during offshore activity, involving different aspects of the ship's mission profile.

Concurrent collection of navigability and operator performance data has the advantage of providing an objective account of the various factors that contribute to ship's overall performance in ice. A ship's ice transiting capability is determined by both the characteristics of the vessel and the piloting behaviour of the operator. Neither of these factors in isolation is sufficient to describe this performance.

2.2 Matrix of Shiphandling Scenarios

In the course of data collection for the development of shiphandling scenarios it became clear that the data were part of a much larger matrix of scenarios. We have identified a number of different types of scenarios that would fill the cells of this matrix. A summary of the matrix is shown in Table 2.1; the complete matrix is found in Appendix B.

Distinctions based on types of operations, types of ice conditions and geographic locations were thought to be essential for this matrix. Western Arctic and eastern Arctic scenarios that involve transiting ships vary according to ice type (sea ice and/or glacial ice), ice concentration, sea and swell conditions, ship's particulars, ship's mission, absence or presence of icebreaker escort, geographical location, time of year, marine weather and visibility. Western Arctic scenarios that involve support operations related to offshore exploration and development (artificial islands, bottom-founded structures, drillships or moored drilling platforms) will vary according to ice type, ice concentration, sea and swell conditions, ship's particulars, ship's mission, number of ships in support fleet, geographical location, time of year, marine weather and visibility.

The matrix was constructed as follows. Geographic locations were selected according to present and projected merchant marine and offshore practice. Locations shown in this list are those generally along routes used by ships on commercial charter, ships involved with the eastern Arctic

Table 2.1 Arctic Piloting Matrix: A Summary

Scenarios

Eastern Arctic: Summer, Fall

Independent Passage:

Complex encounters with glacial ice (bergy water)
Complex encounters with glacial ice and sea ice (bergy water)
Simple encounters with icebergs, bergy bits and/or growlers (bergy water)
Simple encounters with icebergs, bergy bits and/or growlers with sea-ice
Transits of very open to open old or first year pack ice
Transits of close to very close old or first year pack ice
Transits of compact or consolidated, old or first year ice
Transits of pressured ice, close to compact pack, old or first year

Passage of Conducted Ship during Escort:

Following icebreaker under conditions of
- open old or first year pack ice
- close to very close old or first year pack ice
- compact or consolidated old ice or first year ice
- pressured ice, close to compact pack, old or first year ice

Passage of Conducting Ship during Escort:

Escort operations in open old or first year pack ice
Breaking a track under conditions of
- close to very close old or first year pack ice
- compact or consolidated, old or first year ice
- pressured ice, close to compact pack, old or first year ice

Breaking a tract next to a previously broken track under conditions of
- compact or consolidated, old or first year ice
- pressured ice, close to compact pack, old or first year ice

Eastern Arctic: Winter, Spring

Independent Passage:

Complex encounters with glacial ice and sea ice (bergy water)
Simple encounters with icebergs, bergy bits and/or growlers with sea-ice
Transits of close to very close old or first year pack ice
Transits of compact or consolidated old ice or first year ice
Transits of pressured ice, close to compact pack, old or first year

Passage of Conducted Ship during Escort:

Following in track under conditions of
- close to very close old or first year pack ice
- compact or consolidated, old or first year ice
- pressured ice, close to compact pack, old or first year ice

Eastern Arctic: Winter, Spring (cont'd)

Passage of Conducting Ship during Escort:

Breaking a track under conditions of
- close to very close old or first year pack ice
- compact or consolidated, old or first year ice
- pressured ice, close to compact pack, old or first year ice

Breaking a tract next to a previously broken track under conditions of
- compact or consolidated, old or first year ice
- pressured ice, close to compact pack, old or first year ice

Western Arctic: Summer, Fall (Route-Specific Operations)

Independent Passage:

Transits of very open to open old or first year pack ice
Transits of close to very close old or first year pack ice
Transits of compact or consolidated, old or first year ice
Transits of pressured ice, close to compact pack, old or first year

Passage of Conducted Ship during Escort:

Following icebreaker under conditions of
- open old or first year pack ice
- close to very close old or first year pack ice
- compact or consolidated old ice or first year ice
- pressured ice, close to compact pack, old or first year ice

Passage of Conducting Ship during Escort:

Escort operations in open old or first year pack ice
Breaking a track under conditions of
- close to very close old or first year pack ice
- compact or consolidated, old or first year ice
- pressured ice, close to compact pack, old or first year ice

Breaking a tract next to a previously broken track under conditions of
- compact or consolidated, old or first year ice
- pressured ice, close to compact pack, old or first year ice

Western Arctic: Winter, Spring (Route-Specific Operations)

Independent Passage:

Transits of close to very close old or first year pack ice
Transits of compact or consolidated, old ice or first year ice
Transits of pressured ice, close to compact pack, old or first year

Western Arctic: Winter, Spring (Route-Specific Operations, cont'd)

Passage of Conducted Ship during Escort:

Following in track under conditions of
- close to very close old or first year pack ice
- compact or consolidated old ice or first year ice
- pressured ice, close to compact pack, old or first year ice

Passage of Conducting Ship during Escort:

Breaking a track under conditions of
- close to very close old or first year pack ice
- compact, consolidated, or old ice or first year ice
- pressured ice, close to compact pack, old or first year ice

Breaking a tract next to a previously broken track under conditions of
- compact or consolidated, old or first year ice
- pressured ice, close to compact pack, old or first year ice

Western Arctic: Spring (Site-Specific Operations)

Ice management during break-up, in support of site-specific drilling operations:
Close tactical defense slightly updrift
Tactical defense some distance updrift
Reconnaissance at greater range from drill-site

Western Arctic: Summer (Site-Specific Operations)

Ice management during open water period, in support of site-specific drilling operations:
Close tactical defense slightly updrift
Tactical defense some distance updrift
Reconnaissance at greater range from drill-site

Western Arctic: Fall (Site-Specific Operations)

Ice management during freeze-up, in support of site-specific drilling operations:
Close tactical defense slightly updrift
Tactical defense some distance updrift
Reconnaissance at greater range from drill-site

Western Arctic: Winter (Site-Specific Operations)

There are no relevant site-specific marine or ship-related operations that take place at this time of the year other than dedicated ship trials.

sealift, ships involved with resupply and escort operations in the western Arctic, and Canadian Coast Guard icebreakers on northern assignment. It is recognized that some of the locations listed in Appendix B are restricted to shallow draft (small displacement) ships, due to shoal depths or sill depths or other bathymetric constraints. We have indicated in the Appendix the situations for which navigability and/or performance data exist. In instances where navigability and operator performance data have both been collected, they were not always collected at the same time.

The number of geographic locations is large. This reflects the fact that similar ice conditions in different geographic locations do not always present the same situations for piloting. For example, coastlines, channels, tide and currents can pose substantially different challenges for mariners. This means that the different locations should be listed individually. For some geographic locations, there are some types of ice conditions that never, or very infrequently, occur. Accordingly, these situations have been omitted from this list. Because site-specific operations in western Arctic waters do not fully lend themselves to the matrix approach adopted for route-specific operations, we have included a number of these offshore operations in a slightly different format.

2.3 Use of Scenarios in Shiphandling Simulators

The scenarios in this matrix can be used in a number of ways during the development and operation of a simulator. These include guidelines for hardware acquisition, delineation of research and training exercises, and simulator validation. We believe that all of these scenarios could be implemented on a shiphandling simulator with the exception of site-specific operations other than ice defense.

2.3.1 Generic Scenarios

A very general, or generic, account of operations can help to define and guide the hardware acquisition for a simulator. A generic scenario, therefore, is a generalized or "broad brush" description that outlines a type of ship operation or piloting procedure that is important from a training or research point of view. For example, "piloting a ship in pressured ice" is a generic scenario; "backing and ramming in ridged old ice" is another. The simulator hardware must provide the horizontal and vertical fields of view and the extent of platform motion that characterize these operations in the real world. By identifying the operations that need to be simulated, the hardware requirements for the simulator can be established at an early stage of the design and procurement process. In addition, generic scenarios provide a focus for future shipboard data collection - what are the gaps in the data record, where should further navigability and operator performance data be collected?

2.3.2 Training and Research Scenarios

A more specific account of ship's operations, ice or sea conditions, environmental parameters, and piloting considerations is required to use

the simulator for research or training. These accounts constitute the scenarios that masters, officers, and other "trainees" would actually use in a simulator. For example, if a late-season transit of Lancaster Sound is to be simulated, then an explicit specification of all relevant meteorological, oceanographic and ice-related data, plus hydrographic charts and synthetic aperature radar (SAR), on Lancaster Sound at this time of year must be available. In other words, these scenarios contain all information necessary to simulate an operational situation. This includes actual SAR and weather/wind information, the time of transit, routing particulars, and ice regime. The latter includes type of ice, concentration, percent deformation, ridge frequency, distribution of leads or fractures, and other factors.

2.3.3 Validation Scenarios

Finally, a comprehensive account of ice conditions, hazard distributions, piloting procedures, and other observations can help to validate the performance of a simulator. A scenario of this type must be based on shipboard navigability and operator performance data, in addition to all information specified for research/training scenarios. A scenario based on extensive data collected aboard ships allows a master's performance in a simulator to be compared with what was done during the actual transit. The comparison provides a quantitative basis upon which to judge the acceptability of the simulator's equations of motion and the representation of the visual scene. These scenarios are not intended as a means of testing or evaluating the performance of the master, either in the simulator or on the ship. The goal is to compare operator performance in shipboard and simulation environments. If performance in the simulator differs markedly from the actual actions prompted by real world events, then either the equations of motion or visual scene representation is most likely flawed. Validating the performance of the simulator is fundamental to the successful operation of the facility.

2.3.4 Information Requirements for Simulation

For training/research and validation scenarios, we believe that SAR imagery must be used to define an ice regime that programmers will convert into a model of the visual world. Additional information that is needed for simulation programming, and provided to "trainees" during the simulation exercise, includes a hard copy of the SAR imagery of the gaming area (and/or a digital SAR record that can be displayed on a video terminal), a bathymetric or hydrographic chart of the area, a set of waypoints to constrain piloting to a corridor through the region, a set of facsimile ice charts, a sailing guide or pilot book for the route, and data on wind speed, wind direction, and visibility. (A more complete account of information sources for navigation and piloting decisions is found in Appendix D). It is the task of the "trainees" to interpret the SAR, and obtain information from the ice charts. The object here is to provide the trainees with the same type, quality, and volume of information that is typically available on ships.

The growing database of navigability information at TDC and Coast Guard Northern is tailor-made for constructing these training/research

scenarios, if SAR, SLAR, or other good ice data is available for voyages in the database. In a small number of instances, navigability and operator performance data have been collected in a concurrent fashion. This type of data collection strategy holds the most promise for simulator validation.

2.4 Development of Western and Eastern Arctic Scenarios

The factors that contribute to different types of simulator scenarios in the western and eastern Arctic were described in Section 2.2. Some of the scenarios that can be produced by combining these factors are not related to current merchant marine or Arctic offshore operations. For example, the transit of an Arctic Class 8 or 10 icebreaking tanker through either the western or eastern Arctic (or both) is a scenario with no operational, "real world" counterpart. Of the many scenarios that can be identified, the first set developed for shiphandling simulators should consist of situations often encountered during present-day ship operations or offshore activity. In eastern Arctic waters, these situations include navigation incidents consisting of complex (dependent) encounters with glacial ice only, or with glacial ice and sea ice in the same area; more "simple" (independent or discrete) encounters with iceberg(s), bergy bit(s), or growler(s); route sector transits of very open to open old or first year pack ice; route sector transits of close to compact old or first year pack ice; passages with icebreaker escort through different types and/or concentrations of sea ice; berthing; and early season, mid-season, or late season scheduling for any of these circumstances. In the western Arctic, the set of scenarios should include incidents or sequences related to ice management some distance up-drift of the drillship; ice management up-drift of the drillship at close tactical or tactical range; escort after break-out; break-out itself; towing; and day/night or seasonal variations for any of these situations. Although ice management during anchor handling is an essential part of offshore operations in the western Arctic, we believe that its interactive, multiple ship character is beyond the capability of current simulation techniques.

It is not possible to present scenarios for all of these situations in this report, since a number of the them did not occur when we were aboard ships in the western and eastern Arctic. Some of the more important scenarios could not be prepared, since the information required to do this does not exist.

The next part of this section describes the methods used to prepare the simulator scenarios. We have included in Table 2.2 and Figure 2.1 an example based on piloting in the eastern Arctic. Sixteen detailed scenarios and accompanying encounter diagrams are found in Appendix A (submitted to TDC under separate cover). Encounter diagrams are composite illustrations consisting of an operating environment and a series of transparent overlays that show different piloting circumstances during a specified transit interval. The encounter description and encounter diagram concept were developed by Polar Sea Reseearch Ltd., based on work during a previous project (Lowings, 1984).

Table 2.2 Example of Encounter Description

Incident 6 (glacial ice encounter, high sea state present)

time period:

1000h UT to 1200h UT on 840913

visibility:

15+ miles, some sea spray, excellent visibility, daylight conditions at TD

ship data:

12.4 kt on course 092, 95 rpm on shaft, 10 cm radar operating at TD

synopsis:

Incident starts on completion of routing change to 092 at 1030h. Target lay dead ahead on radar at 12.7 miles at this time. Course altered to 094 at 1102h, 095 at 1103h. This target, an iceberg, passed aft of vessel 1/4 mile to port at 1131h. 2 growlers were 1/8 mile to port as this close approach took place; a third growler lay 1 cbl stbd. This growler was abaft of ship before it was detected, due to following sea, breaking waves, and pronounced glare on sea surface. Course brought to 093 at 1132h. No speed or autopilot changes made by watch officer during this part of incident.

Incident continues 1135h. Course changed to 095, ending on 098, to avoid 2 growlers detected roughly 1/2 mile dead ahead at this time. These growlers passed aft 1/2 cbl and 1 cbl port at 1138h. A third growler, not detected before it lay abaft, was 50 m to stbd at these close approaches. A large, low freeboard growler detected dead ahead at 1139h, roughly 2 ship lengths distant. Course altered to 102 immediately. Close approach was 20 m port at 1140h. Confused/following sea state at this time made growler detection very difficult. Transit speed not changed during second part of incident; autopilot engaged, as was.

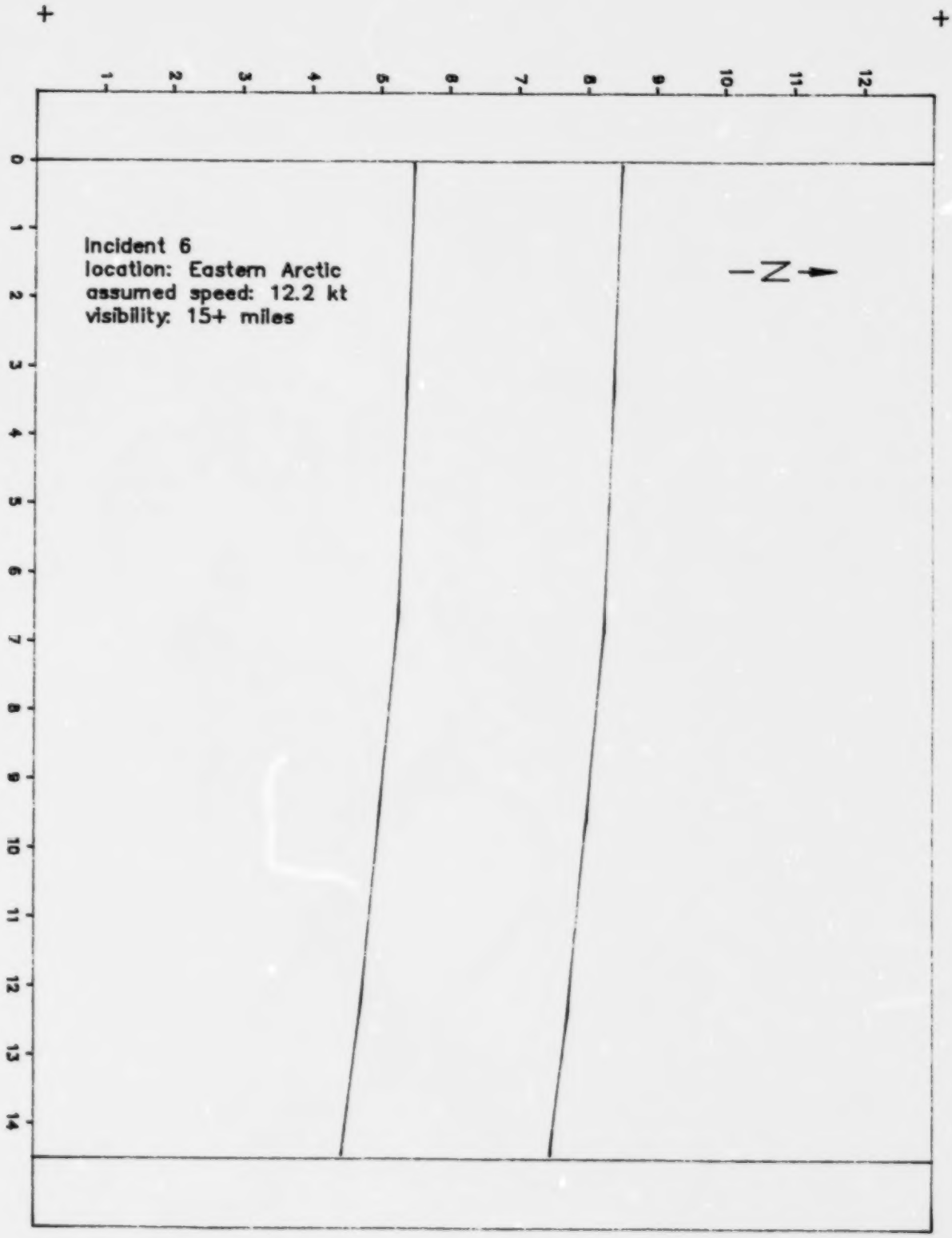

Figure 2.1 Example of Composite Vector Diagram

2.5 Scenario Construction

The scenarios were constructed as follows. First, our navigability observations on hazard detection and avoidance, or accounts of offshore operations, were used to prepare computer generated vector diagrams of the gaming areas. These gaming areas show the actual distribution of ice hazards, any other ships, or sea ice conditions during an observation or critical incident period. Each gaming area, therefore, is "fixed" in time and space by this procedure. Next, a set of constraints or boundary conditions was described for each area, by specifying the colour, luminance, sea state, visibility, marine weather, ice conditions and other piloting considerations present at the time. The final part of this assembly process was to define the ship's task, or mission objective, in the gaming area. For the eastern Arctic situations, this task involved passage of the ship through the gaming area, from position A at one "edge" of the region to position B at the other "edge". In the western Arctic, it represented the completion of specified operations in the gaming area, based on instructions given to the vessel by the drillship master or drilling superintendent.

To construct the eastern Arctic gaming areas, it was necessary to assume that ship's speed was constant at any given engine setting during the incidents that the gaming areas are based on. The complex chronology of detecting, approaching and encountering various types of hazards can be plotted on this basis only, since a continuous speed and position record was not available on the ship. Hourly or half-hourly positions from the ship's satellite navigation system were used to calculate distance made good, which, in turn, was used to plot both the piloting and hazard data. However, we must emphasize that assuming constant speed to construct the scenario does not mean that constant speed must be used to work with the scenario in the simulator. In other words, ship's speed in the simulator is not constrained by the constant speed used to construct each gaming area. Ship's speed in the gaming area can be varied as often as liked.

In addition, the plotting procedure assumes that all targets are stationary in the eastern Arctic, and with the exception of crossing ships or other vessels in transit, that all targets do not "move" in the gaming area. However, lack of motion is not always the case in these waters. For example, along the west coast of Greenland, in Lancaster Sound, and elsewhere, icebergs and bergy bits can be appreciably set (or moved) by wind stress and surface currents during the course of an incident. To a lesser extent, pack ice is subject to these forces as well. This type of dynamic situation is very difficult to depict on a static display. Where possible, we have attempted to indicate drift by plotting a drift vector between the initial and final locations of some targets in the gaming area. These locations were determined from radar ranges and bearings that were taken at different stages of the original (source) incidents. It is mentioned that target motion can be introduced to a scenario running on a simulator. The motion can be generated from the drift vector(s) shown on the plot(s) of the gaming area(s).

Some major differences between our eastern and western Arctic scenarios are noted. These differences pertain to different types of ship operations that take place in these waters. In eastern Arctic regions, almost all ship operations are route-specific. Merchant ships proceed on

specified routes at specified speeds and headings, generally from one port or destination to the next. In the western Arctic, the situation is fundamentally different. Ship operations during offshore drilling in the Beaufort Sea are almost entirely site-specific. The basic mission of icebreakers and supply vessels is to support drilling from artificial islands, bottom-founded structures, or moored drillships and drilling units. Except for escort to or from the drillsite, towing, re-supply operations from shore bases to the drillsite, and ice reconnaissance well up-drift, all ship operations take place at close range to stationary platforms. Furthermore, these operations are controlled, scheduled, and directed by personnel on the platform, not personnel on the ships. We also mention relative motion differences. In the eastern Arctic, pack ice is stationary or almost stationary compared to any ship that makes way through it, with the exceptions of tidally-pumped or current-related ice drift in some locations. Similarly, icebergs, bergy bits, and growlers are stationary or almost stationary targets. In the western Arctic, in the vicinity of a drillship, pack ice typically drifts past the drillship; ice defense operations carried out by support fleets involve management of a large "moving" target, or a series of smaller "moving" targets.

The gaming areas for eastern Arctic scenarios are constrained by the limitations related to data collection on the ship. This is also true for western Arctic situations. For purposes of realistic simulation, it is necessary for the operator in a simulator to encounter roughly the same type, variety, and distribution of ice hazards that were encountered by a master or officer on a ship during actual operations. In other words, if an eastern Arctic gaming area is to adequately resemble the real world, then the route through the region must pass through a set of specified waypoints. These waypoints describe a corridor through the gaming area that is sufficiently wide to give the operator some piloting flexibility, but sufficiently narrow to ensure that many of the same encounters that took place on the ship take place in the simulator. We selected a corridor 3 miles wide, centred on the actual track, as an optimal choice here. This is because the density of plotted hazards can only be most accurate for the narrow corridor actually transited by the ship during an incident or an encounter that the gaming area is based on. It is simply not possible in the field to record all (or most) hazards that lay off the port or stbd quarter, when the hazards of greatest interest, and greatest risk to the ship, are those directly ahead or bearing only slightly off the ship's bow. If the transit through the gaming area cannot be confined in some sense to specified corridors, much of the benefit of using actual incident histories to construct different simulator scenarios will be lost.

3. TASK ANALYSIS OF EASTERN AND WESTERN ARCTIC SCENARIOS

3.1 Fall Voyages 1984

Eight incidents were selected from among the more than thirty task analysis episodes recorded during the fall of 1984. The incidents correspond to the scenarios described in Appendix A and were selected to sample the variety of environments and tasks encountered during the Thuleland and Kigoriak voyages. Table 3.1 summarizes the conditions which were sampled in each scenario. A detailed presentation of descriptive statistics and an analysis of the stochastic structure of all recorded episodes can be found in Donderi and Ostry (1986). The implications of the findings for marine technology and manning are discussed in Section 3.4.

Table 3.1 Scenarios from the Thuleland and Kigoriak Voyages

Title	Ship	Description
Date	Analysis duration (hrs:mins)	
Incident 1	Thuleland	Complex episode in Baffin Bay involving encounters with icebergs and sea ice.
840904	1:05	
Incident 2	Thuleland	Second episode involving glacial and sea ice.
840905	1:16	
	Thuleland	Docking at Little Cornwallis Island.
840908	0:27	
Incident 6	Thuleland	Passage through Lancaster Sound at night.
840909	0:13	
Incident 1	Kigoriak	Breaking up ice flows updrift of the drillship Explorer III at night.
841016	1:47	
Incident 2	Kigoriak	Ice defense while supply boats lift anchors of drillship at night.
841018	2:37	
Incident 3	Kigoriak	Ice defense while supply boats set drillship anchors.
841021	1:00	
Incident 4	Kigoriak	Ice defense updrift and close by drillship and supply boats to maintain drillship on station.
841022	1:56	

Task analysis data collection methods were described fully in a previous report (Donderi and Ostry, 1985). In brief, one or more observers recorded activities and positions of officers and crew on the bridge every fifteen seconds during episodes ranging from twenty minutes to four hours in length. The recorded data were transcribed and entered into computer files. Summaries were made of the frequency with which activities were recorded over all of the sampling intervals, and of the sequences of particular activities carried out and positions occupied by various officers and crew.

The immediate goal in analyzing the data from the scenarios was to document the difference in the pattern of bridge activities observed aboard the two ships. There are 11 hours and 20 minutes of task analysis data from Kigoriak and 6 hours and 42 minutes of comparable data from Thuleland.

The differences in activity patterns are caused by several factors. First is the difference between the missions of the two ships: the Thuleland carrying cargo out of the eastern Arctic, the Kigoriak supporting drillship operations in the western Arctic. Second is the difference in bridge design. The Thuleland has a conventional bridge (Figure 3.1), the Kigoriak has a bridge of unconventional design which features a one-person workstation (Figure 3.2). These differences are associated with differences in personnel practices. The officers and crew of the Thuleland stand conventional watches, with extra personnel assigned in ice-covered water. The Kigoriak is designed for one-person operation, and in fact is often operated by a single officer on a twelve-hour watch.

The difference in mission is apparent in comparing the frequency of course changes on the two ships. In many of its missions, the Kigoriak continually manoeuvred at close quarters around other ships. Course changes were much more frequent aboard Kigoriak than aboard Thuleland. Table 3.2 illustrates the difference in proportion of sampling intervals in which course changes were recorded aboard Thuleland and Kigoriak over all of the scenarios.

A contrasting difference is found in the frequency with which chart table activities take place aboard the two ships. While supporting a drillship on site, the Kigoriak has restricted freedom of movement. Its manoeuvres are too frequent and unpredictable to be charted. Under these circumstances, almost no chart-table activities occur. Table 3.2 illustrates the difference in proportion of chart table activity between Thuleland and Kigoriak across the four scenarios described for each ship.

A characteristic of the Kigoriak's drillship support activity is the amount of work at night, and the importance of good night visibility. Aboard Kigoriak and the other supply boats of the Canmar fleet, night visibility is provided by movable Xenon-arc searchlights. Kigoriak mounted six searchlights. Two pairs of two searchlights each were mounted on the superstructure one deck below the bridge, one pair to port and one to starboard. Two more searchlights were individually mounted on the forecastle, port and starboard of the bow. These individually moveable searchlights are controlled by joysticks which both rotate and elevate the lights. Beam focus can also be remotely controlled from the bridge.

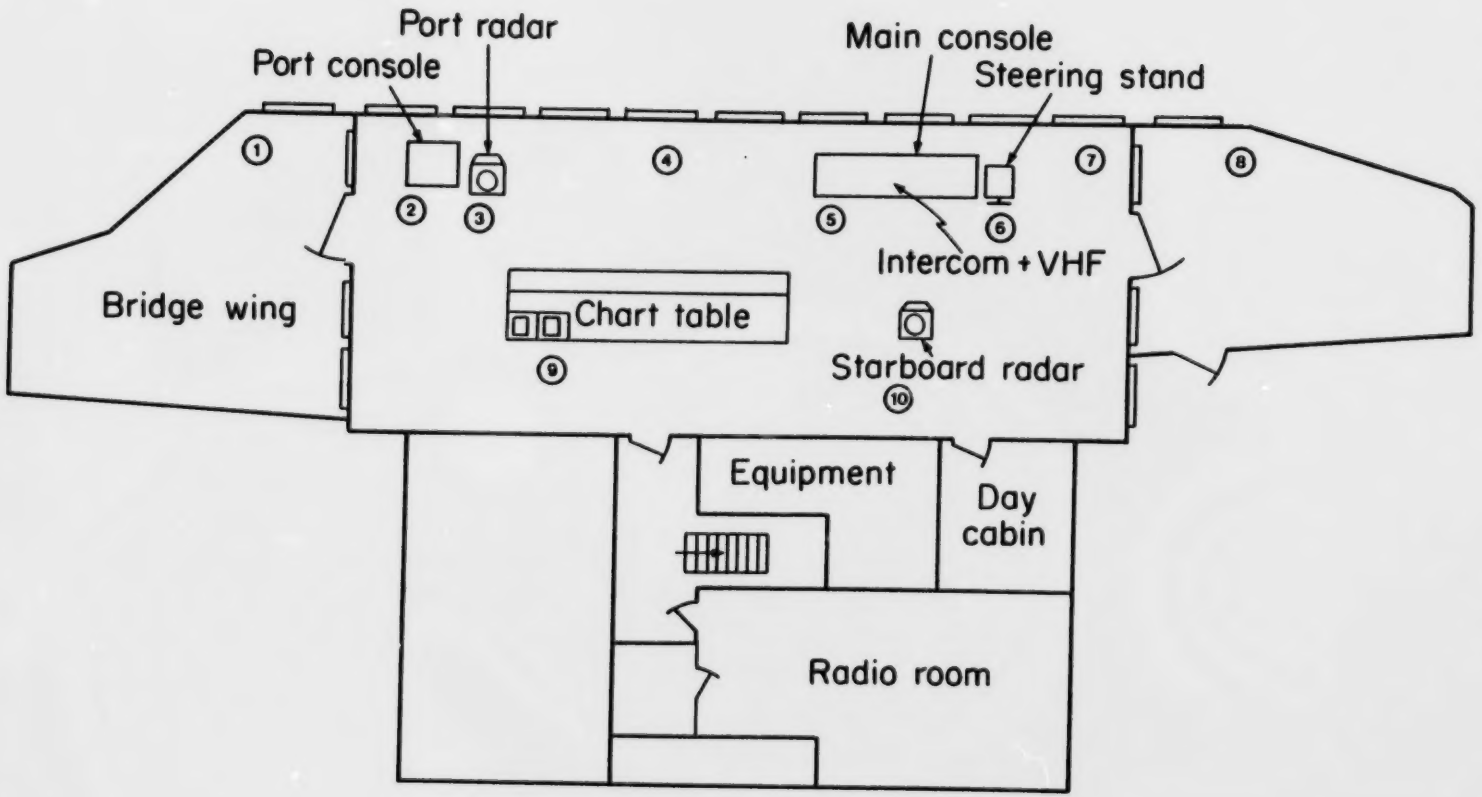

Figure 3.1 Bridge of the M.S. Thuleland

Bridge of M.V. Canmar Kigoriak, October 1984

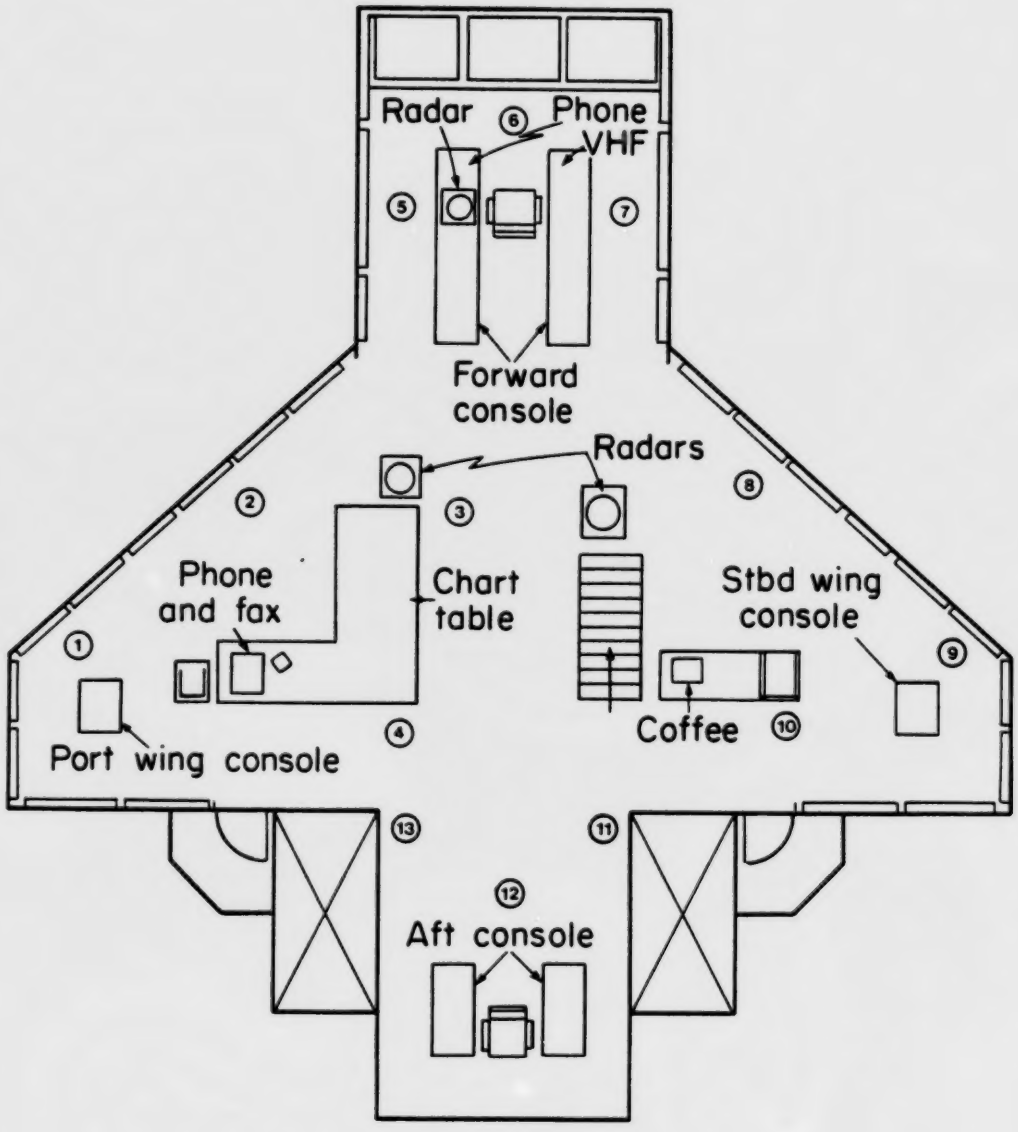

Figure 3.2 Bridge of the M.V. Canmar Kigoriak

Table 3.2 Percentage of Course Change and Charting Activity for Officers aboard Thuleland and Kigoriak

Ship and officer	Percentage of sampling intervals containing: Course change	Chart table
Thuleland		
Master	0.2	26.4
R. Master	1.9	3.2
R. Master 2	1.2	18.5
1st Mate	0.7	28.1
2nd Mate	0.0	0.0
3rd Mate	6.1	11.9
Kigoriak - Fall 1984		
Master	56.1	1.4
1st Mate	37.1	0.0
2nd Mate	19.6	0.4
Kigoriak - Spring 1985		
Master	31.9	5.1
1st Mate	78.6	0.0
R. 1st Mate	43.0	14.0
2nd Mate	49.5	0.7
R. Master	36.0	0.0

Controlling these lights was an important activity at night aboard the Kigoriak. There was no comparable activity recorded during tasks analysis aboard Thuleland. However the searchlights were used regularly and a bow-mounted searchlight was manipulated as needed. Aboard Kigoriak, a common method of operation was for the master and the mate to cooperate in piloting the ship and operating the lights. The master would operate the engine and rudder controls, and the mate would stand alongside and operate the light controls either with or without instruction.

During the two Kigoriak night scenarios, the master was observed to operate the lights during seven and twenty percent of the recorded sampling intervals. During the same two scenarios, the second mate was observed to operate the lights on fifty and forty-seven percent of the recorded sampling intervals. Thus the operation of movable searchlights is an important component of night drillship support.

Differences between Thuleland and Kigoriak were also evident in observation and communications activities. Table 3.3 shows that the Thuleland officers used binoculars more frequently, and spoke over the phone, intercom or VHF radio ("phone" communications) less frequently than Kigoriak officers. Kigoriak manoeuvring is done at close range. Binoculars are not needed aboard Kigoriak, as they are aboard Thuleland, to

observe icebergs or to identify ice types. Kigoriak's operations take place against a background of important open-channel VHF communications: for example, ice drift reports, discussions about ice defense tactics with the drillship and supply boat masters, aviation reports and weather reports. Many of these communications are directed at Kigoriak, and must be acknowledged by Kigoriak.

Table 3.3 Percentage of Sampling Intervals with Radar Use, Binocular Use, Voice Communication or Phone Communication (Inside and Off-ship) Communication for Officers aboard Thuleland and Kigoriak.

Ship and officer	Activity sampled			
	Radar	Binoculars	Voice	Phone
Thuleland				
Master	14.5	0.2	5.1	0.2
R. Master	24.4	8.3	5.1	1.9
R. Master 2	12.3	0.0	1.2	0.0
1st Mate	15.0	4.4	9.9	0.4
2nd Mate	18.4	22.4	28.6	0.0
3rd Mate	11.2	21.1	12.3	0.4
Kigoriak - Fall 1984				
Master	6.8	1.1	4.4	4.9
1st Mate	12.2	0.0	12.2	12.2
2nd Mate	13.6	0.2	4.9	12.2
Kigoriak - Spring 1985				
Master	0.0	4.0	14.7	20.7
1st Mate	0.0	0.0	5.1	6.5
R. 1st Mate	0.0	2.5	7.9	5.0
2nd Mate	0.0	0.0	3.9	3.4
R. Master	0.0	0.5	2.0	13.2

Table 3.3 indicates that during the fall of 1984 the frequency of radar use was about the same for the two ships. However, the use of radar differs aboard each ship. Aboard Kigoriak, radar is used for ranging on fixed targets like the drillship, and for monitoring ranges in close quarters where the relative bearings of large targets like the drillship and supply ships are visually obvious if visibility is good. Under these conditions, the important small targets -- ridges, buoys and anchor cables -- must be identified visually. The searchlights are vital in this work at night.

Another important use of radar aboard the Kigoriak during ice management updrift of the drillship was to verify that the bearing of Kigoriak's track to the drillship matched the bearing of the ice drift

relative to the drillship. Breaking ice off the drift track is not beneficial because the broken ice passes clear of the drillship whereas the unbroken ice may drift directly down on it. A typical ice management pattern is to proceed a fixed distance up-drift -- often several miles -- and then come about and return on a parallel track to the drillship. Both the range and the bearing from the drillship are periodically verified by using radar.

Thuleland radar use involves the tracking of icebergs, sea ice, and conventional marine targets. The median length of radar observation was approximately fifteen seconds. Over the entire set of Thuleland task analysis data, the master made a radar observation, on average, every two minutes. The distribution of radar observation lengths and inter-observation intervals was highly skewed, as illustrated in Figure 3.3. Comparable data from one scenario aboard Kigoriak during ice management up-drift, at night, indicated a median observation duration of fifteen seconds and a median interval between observations of about one per minute.

Differences in ship mission, bridge design and personnel policy combine to produce different patterns of position and movement aboard Thuleland and Kigoriak.

Kigoriak's triangular bridge plan and one-person workstation produce a concentration of time spent by master and mate in one place: literally in one chair from which the ship can be conned. Across the entire task analysis sample, the Kigoriak master spent sixty percent of his time in the workstation, ten percent standing directly alongside the workstation, and less than one percent of his time at the chart table. By contrast, the Thuleland master spent twenty-three percent of his time (the highest for any location) along the open centre of the bridge: a much larger area than the Kigoriak workstation. He spent twelve percent of his time at the chart table. The average percent of time spent in walking from one place to another by the Thuleland officers was 5.7 percent. The comparable figure for the four officers aboard Kigoriak was 1.4 percent. Much less time was spent walking around the Kigoriak bridge, even though it is in fact a large bridge (about thirty square meters).

Task analysis of activity and position data from the Thuleland and Kigoriak voyages documents important differences in piloting and communications procedures between the two ships. A combination of mission and design differences lead to less movement, less chart table work, more electronic communication, and far more manoeuvring aboard the Kigoriak in the Beaufort Sea. The Thuleland was conned from a conventional bridge. During open water navigation to Little Cornwallis Island in September 1984, binoculars, radar and night vision devices were used extensively to identify ice targets at night. Relatively little manoeuvring was done, chart-table work occupied a large percentage of time, and off-ship communications were minimal. These differences should be reflected in the design of simulator scenarios for the eastern and western Arctic.

3.2 Spring Voyage 1985

The data described in this Section were collected during the incidents reported in Appendix A. These data are summarized in Tables 3.2 and 3.3. A more detailed presentation is found in Appendix C.

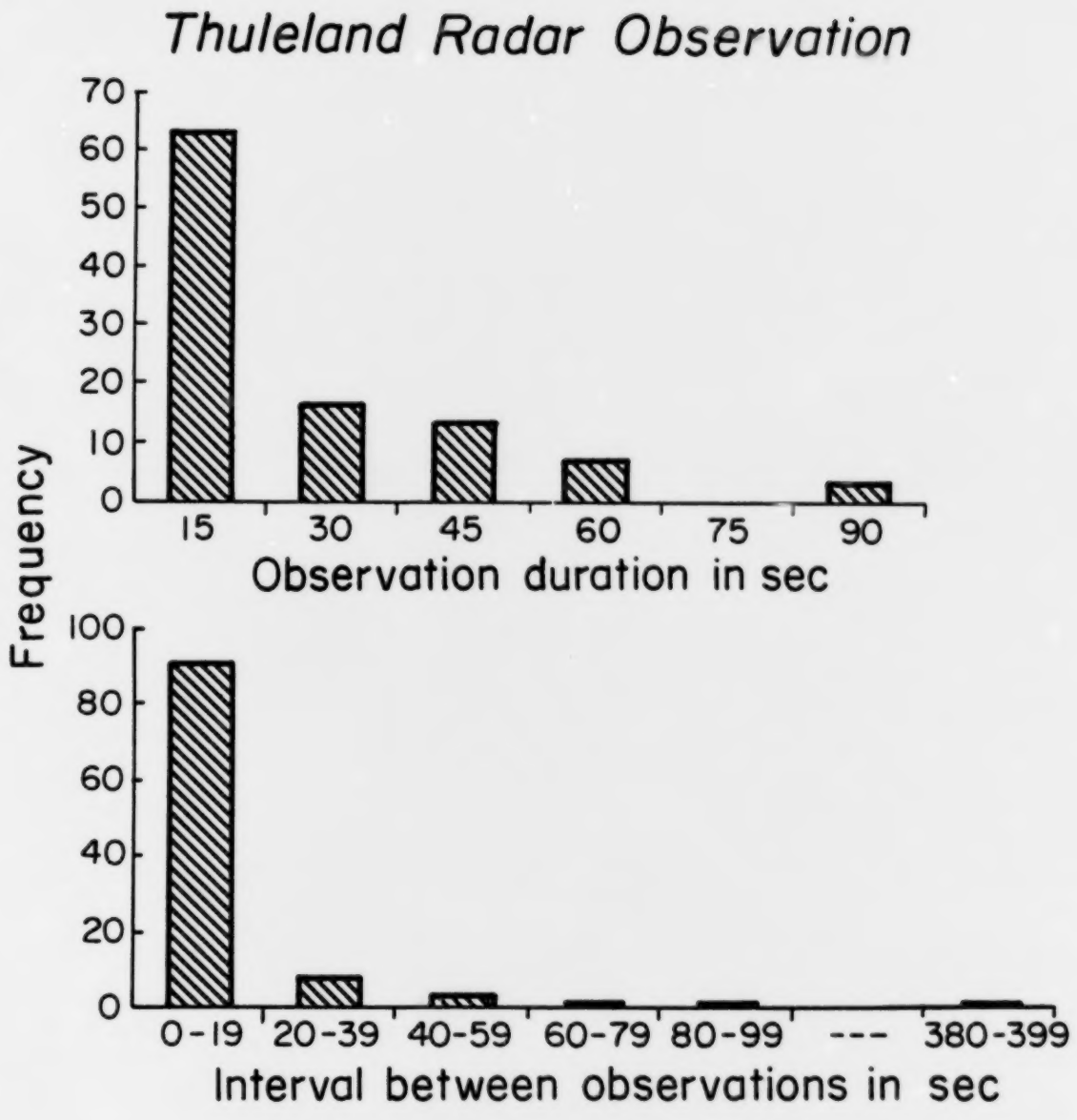

Figure 3.3 Duration of Radar Observations and Intervals Between Radar Observations for the Master, M.V. Thuleland

Activities recorded aboard Kigoriak in the spring of 1985 differed from those recorded during the fall of 1984. Differences both in mission and in equipment were responsible for the variation in these activities. During the spring of 1985 Kigoriak was engaged in break-out from McKinley Bay. Few other ships were underway at the same time. No drilling operations were in progress. The ship was often stopped in ice waiting for instructions. As a result, operator workload was less during the spring. However in some respects, the workload during break-out was comparable to the workload during the fall of 1984. This is shown, for example, by the frequency of course changes in Table 3.2.

There were differences in bridge equipment between the fall of 1984 and the spring of 1985. Two instruments available in spring 1985 were not available in the fall of 1984. One was a Krupp-Atlas daylight radar display, which was mounted adjacent to the chart table in place of an older radar. The other was a real-time microwave positioning system ("mini-ranger") which was used to guide Kigoriak (and other vessels) in and out of the anchorage through the narrow dredged channel to the ten metre line. The new radar was used infrequently, but on one occasion was relied on when the "mini-ranger" malfunctioned due to vibration damage. The "mini-ranger" display was used to locate the entrance to the dredged channel, to proceed along the dredged channel and to operate in the anchorage. This display was located facing the seated conning position at the forward console, below the line of sight, at the extreme forward end of the bridge.

The "mini-ranger" display shows a north-up plan view of the ship and McKinley Bay operations area. The display is updated continuously and so provides a real-time record of ship's position. It is essential for proceeding to and from the anchorage and in many instances is the primary means of determining the ship's position in water depths of greater than ten metres. The display is divided into two fields: the entire channel and basin layout in the left half of the display and an enlarged view of the ship's position in the right. A small rectangle in the left field shows the position of the right field display. In the enlarged part, the ship's location is displayed relative to an imaginary navigational marker at the "edge" of the screen. Below the graphical part of the display, the range and bearing are shown relative to this marker. The distance from the side of the channel to the ship is also shown. For example, S38 indicates that the ship is 38 metres starboard of the west side of the channel assuming a north-up reference. When the ship reaches the edge of the enlarged field both parts of the display are updated. An improvement in this display would be to show the distance to port or starboard from the ship to the closest side of the channel rather than vice versa.

Table 3.2 shows that more time was spent at the chart table aboard Kigoriak in the spring of 1985 than in the fall of 1984. This may be due to the less critical or less urgent nature of the operations during break-out compared to ice defense during drillship operations. Nevertheless, Table 3.3 shows that communications remained frequent aboard Kigoriak relative to Thuleland.

Because the Kigoriak's thrust and rudder are both controlled by a single operator, the frequency of control activities by officers is high aboard Kigoriak. This was true in spring 1985 as well as in fall 1984 (Table 3.3).

3.3 Stochastic Modeling

A detailed presentation of descriptive statistics and an evaluation of the stochastic characteristics of bridge activities on the Kigoriak, Thuleland, and M.V. Arctic are reported in Donderi and Ostry (1986). In general, activity sequences for masters were highly structured. The occurrence of each activity was predictable from a sequence of one or more preceding activites. Masters' activity sequences were characterized by a recurrence of visual observation (for example, visual observation, communication, visual observation). For most of the the watch officers, each event was predictable from the immediately preceding event. Characteristic sequences were vision - radar observation or vision - communication. Visual observation was a common antecedent or consequence of most other activities.

Although activity sequences were predictable, activity durations were not. An analysis of the duration of radar and communications activities indicated that their distribution was exponential. This means that the termination of an activity was a random process (Feller, 1968).

3.4 Implications for Bridge Design and Manning

Under the high workload conditions of ice defense during anchor handling at night, two people are required on the bridge of Kigoriak. The mate assisted with searchlight control while the captain conned the ship and communicated almost continually with the drillship and with other supply boats. Comments of Kigoriak senior officers indicated that two operators are desired under these conditions. In order to minimize fatigue and to maximize visibility, the assisting officer should be seated, have access to all searchlight controls and communications equipment, and be positioned to relieve the senior officer at short notice.

Aboard Thuleland, we observed a large systematic increase in the number of visual observations per minute as the number of bridge crew increased from one to four (Donderi and Ostry, 1986, Figure 8). An increase in bridge crew size can increase the level of vigilance. Assuming that communications on the bridge are efficient, this can increase the probability of close-range hazard detection. An increased number of watchkeeping personnel on thin-skinned ships in ice-infested waters will likely improve hazard detection, identification and avoidance.

Empirical evidence from two merchant ships shows that the captain is the officer who makes the most frequent visual observations when he is on the bridge. The captain also communicates frequently and makes regular use of radar. The captain should be able to communicate and to use a radar at the optimum positions for visual observation. On a merchant ship, this means on the bridge wings and at a central forward location. Communications equipment, a radar display, and the environmental and ship status displays necessary for piloting should be available at both wings and at a central forward piloting console.

The ship's mission, bridge design and manning differ on Kigoriak and Thuleland. Although it would be desirable to know which of the two designs is preferable, this is not possible; the effectiveness of a given bridge design requires a comparison of ships with a similar mission profile.

4. CONCLUSIONS

This report presents the findings of coordinated task analysis and navigability studies conducted aboard M.S. Thuleland during fall 1984 and M.V. Canmar Kigoriak during fall 1984 and spring 1985. Our objectives were the development of an understanding of the information requirements for Arctic navigation and the elaboration of scenarios of an Arctic shiphandling simulator that are based on actual operations or transits in Arctic waters.

Task analysis and navigability studies both focus on piloting behaviour but do so from different perspectives. Task analysis documents the structure of operator performance during Arctic navigation whereas navigability studies describe the consequences of operator performance when a ship is piloted through ice-covered or ice-infested waters. Navigability studies provide a context to better understand the actions of mariners; task analysis provides information on the changes in workload during navigation in the Arctic. Together these studies provide a framework that better explains the performance of the operator and the piloting of ships than either type of study does individually.

4.1 Simulator Development

Several types of information necessary for simulator development are presented. This includes detailed descriptions of actual operations and operator performance that are the basis for scenarios to be used for training on and validation of an Arctic shiphandling simulator; the information requirements for preparing scenarios to be used for training; a matrix of of simulator scenarios that consists of a seasonal and geographic index of operations in different types of ice conditions; colour and luminance of the Arctic marine environment measured under actual operating conditions; data on the motion of a ship during ramming, backing and maintaining station in ice with engines running.

The main conclusions from these findings are:

Simulator validation must be based on comprehensive accounts of actual operations and quantitative measures of piloting performance in the environments that are to be simulated.

Simulators should be used primarily for training on cognitively oriented bridge procedures and tactical and close tactical decision making. A simulator is not needed to train visual ice identification skills.

The developer of a simulator should buy the best screen and projection system affordable but undue expense should not be incurred to achieve visual fidelity. The visual display should preserve the characteristics by which old and first year sea ice differ to the extent that the display will allow. Care should be taken to equate the detectability of various ice types between the simulator and the environment. If the detectability of any ice type is unrealistically easy or difficult the simulation will give inappropriate training.

In the absence of complete knowledge of the distribution in time and space of ice and environmental conditions in a specific region, the gaming

area for simulator training scenarios should be based on actual SAR imagery. This should be supplemented by information from bathymetric or hydrographic charts, a set of facsimile ice charts, a sailing guide or pilot directions for the region and data on actual wind speed, wind direction and marine visibility. The SAR imagery used to construct the gaming area should be provided to the trainee who, as a part of the simulation exercise, interprets the SAR (and other information) to proceed through the simulated environment.

Motion is an important consideration in simulator design. Since operator control actions are influenced by motions felt on the bridge, it is necessary to know the magnitude and distribution of this motion, the range of operator sensitivity to motion and the relationship between motion and operator control actions. Little data of this type exist. More data on bridge motions should be collected to properly determine the need for a motion platform for a simulator.

The database of navigability and operator performance information is far from complete. There are many piloting situations where navigability and/or operator performance data does not exist. This information is needed not only for purposes of simulation but also for the realistic and accurate assessment of operator workload, risk, and Arctic ship safety. Navigability and operator performance data also provides a quantitative basis for decisions regarding bridge design, manning and regulations development.

4.2 Arctic Navigation Technology

Our data collected on merchant ships and icebreakers indicate that the use of ice observation aids varies as a function of the risk posed by the hazards encountered by the vessel. The use of radar, electronic image intensifiers and binoculars increases with ice concentration and with decreases in visibility. The precise relationship between risk and the use of ice observation aids is unknown.

Night lighting requires high powered, multiple light sources which are easily maintainable, reliable, remotely controlled and focused. Lights should be mounted out of the direct line of sight.

Bandwidth reduction schemes should be devised to promote the wider use of SAR. SAR is the best remote sensing technology at the present time. It is prefered because of its coverage, resolution, timeliness and the clear distinction it usually provides between first year and old ice. SAR should be made available to mariners in a form they are familiar with -- a latitude/longitude grid must be shown on the display.

False colouring and incoherent averaging of ships' radar displays should be explored to reduce visual noise and make the luminance difference between the radar returns of old and first year ice more readily detectable. Under operating conditions, false colouring may make it easier to detect old ice in any open or more concentrated matrix of first year ice.

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Appendix A

ENCOUNTER DIAGRAMS AND DESCRIPTIONS OF SELECTED ARCTIC OPERATIONS

(under separate cover)

Appendix B

MATRIX OF ARCTIC PILOTING SCENARIOS

This appendix contains a comprehensive list of operations related to present-day and projected shipping activities in the western and eastern Arctic. The list, in effect, defines the complete matrix of shiphandling scenarios for the purposes of simulating ship operations in Arctic waters. The matrix includes information on types of operations, types of ice conditions and geographic locations. We have indicated where some types navigability and operator performance data exist. The volume, completeness and quality of these data vary considerably. In particular, even when considerable data are available for some given situation these represent only a sample of a broad range of possibilities. Further details related to the preparation of this matrix are found in Section 2.2.

It is emphasized that in order to utilise these scenarios in an Arctic shiphandling simulator the following additional types of information must be available in each case: SAR or SLAR imagery, bathymetric or hydrographic chart, sailing guide or piloting directions, tide and current information, marine environmental data (wind speed, wind direction, visibility), and facsimile ice charts. In short, the types and sources of information that mariners use on ships in Arctic waters must be available for use in the simulator. In addition, appropriate marine radar and communications simulations are required.

Scenarios	Validation	
Eastern Arctic: Summer, Fall	Navigability	Performance
Independent Passage:		
Complex encounters with glacial ice (bergy water)		
Baffin Bay	x	x
Complex encounters with glacial ice and sea ice (bergy water)		
Baffin Bay	x	x
Simple encounters with icebergs, bergy bits and/or growlers (bergy water)		
Davis Strait	x	x
Baffin Bay	x	x
Hudson Strait	x	
Lancaster Sound	x	x
Jones Sound	x	
Simple encounters with icebergs, bergy bits and/or growlers with sea-ice present		
Baffin Bay	x	x
Hudson Strait	x	
Lancaster Sound	x	x
Jones Sound	x	
Transits of very open to open old or first year pack ice		
Lancaster Sound	x	x
Barrow Strait	x	
McDougall Sound	x	
Baffin Bay	x	
Hudson Strait	x	
Hudson Bay	x	
Fox Basin	x	
Admiralty Inlet	x	
Viscount Melville Sound		
Jones Sound	x	
Wellington Channel		
Norwegian Bay	x	

Scenarios	Validation	
Eastern Arctic: Summer, Fall	Navigability	Performance
Transits of close to very close old or first year pack ice		
Lancaster Sound	x	x
Barrow Strait	x	
McDougall Sound	x	x
Baffin Bay	x	
Hudson Strait		
Hudson Bay		
Fox Basin		
Admiralty Inlet	x	
Viscount Melville Sound		
Jones Sound	x	
Wellington Channel		
Norwegian Bay	x	
Transits of compact or consolidated, old or first year ice		
Lancaster Sound	x	x
Barrow Strait	x	
McDougall Sound		
Baffin Bay	x	
Hudson Strait		
Hudson Bay		
Fox Basin		
Admiralty Inlet	x	x
Viscount Melville Sound		
Jones Sound		
Wellington Channel		
Norwegian Bay	x	
Transits of pressured ice, close to compact concentrations, old or first year		
Lancaster Sound	x	x
Barrow Strait	x	
Baffin Bay	x	
Hudson Strait		
Norwegian Bay	x	
Hell Gate	x	
Cardigan Strait	x	

Scenarios	Validation	
Eastern Arctic: Summer, Fall	Navigability	Performance
Passage of Conducted Ship during Escort:		
Following icebreaker under conditions of		
open old or first year pack ice		
Lancaster Sound	x	
Barrow Strait	x	
McDougall Sound	x	
Baffin Bay	x	
Hudson Strait		
Hudson Bay		
Fox Basin		
Admiralty Inlet		
Viscount Melville Sound		
Jones Sound		
Wellington Channel		
Norwegian Bay		
close to very close old or first year pack ice		
Lancaster Sound	x	
Barrow Strait	x	
McDougall Sound	x	
Baffin Bay	x	
Hudson Strait		
Hudson Bay		
Fox Basin		
Admiralty Inlet		
Viscount Melville Sound		
Jones Sound		
Wellington Channel		
Norwegian Bay		
compact or consolidated old ice or landfast first year ice		
Lancaster Sound	x	x
Barrow Strait	x	
McDougall Sound		
Baffin Bay		
Hudson Strait		
Hudson Bay		
Fox Basin		
Admiralty Inlet	x	x
Viscount Melville Sound		
Jones Sound		
Wellington Channel		
Norwegian Bay		

Scenarios	Validation	
Eastern Arctic: Summer, Fall	Navigability	Performance
pressured ice, close to compact concentrations, old or first year ice		
Lancaster Sound	x	x
Barrow Strait	x	
Baffin Bay	x	
Hudson Strait		
Norwegian Bay		
Hell Gate		
Cardigan Strait		
Passage of Conducting Ship during Escort:		
Escort operations in open old or first year pack ice		
Lancaster Sound		
Barrow Strait		
McDougall Sound		
Baffin Bay		
Hudson Strait		
Hudson Bay		
Fox Basin		
Admiralty Inlet		
Viscount Melville Sound		
Jones Sound	x	x
Wellington Channel		
Norwegian Bay	x	x
Breaking a track under conditions of close to very close old or first year pack ice		
Lancaster Sound		
Barrow Strait		
McDougall Sound		
Baffin Bay		
Hudson Strait		
Hudson Bay		
Fox Basin		
Admiralty Inlet		
Viscount Melville Sound		
Jones Sound	x	x
Wellington Channel		
Norwegian Bay	x	x

Scenarios	Validation	
Eastern Arctic: Summer, Fall	Navigability	Performance
compact, consolidated, or fast old or first year ice		
Lancaster Sound		
Barrow Strait		
McDougall Sound		
Baffin Bay		
Hudson Strait		
Hudson Bay		
Fox Basin		
Admiralty Inlet		
Viscount Melville Sound		
Jones Sound		
Wellington Channel		
Norwegian Bay	x	x
pressured ice, close to compact concentrations, old or first year ice		
Lancaster Sound		
Barrow Strait		
Baffin Bay		
Hudson Strait		
Norwegian Bay	x	x
Hell Gate	x	
Cardigan Strait	x	x
Breaking a tract next to a previously broken track under conditions of:		
compact, consolidated, or fast old or first year ice		
Lancaster Sound		
Barrow Strait		
McDougall Sound		
Baffin Bay		
Hudson Strait		
Hudson Bay		
Fox Basin		
Admiralty Inlet		
Viscount Melville Sound		
Jones Sound		
Wellington Channel		
Norwegian Bay		

Scenarios	Validation	
	Navigability	Performance
Eastern Arctic: Summer, Fall		
pressured ice, close to compact concentrations, old or first year ice		
Lancaster Sound		
Barrow Strait		
Baffin Bay		
Hudson Strait		
Norwegian Bay		
Hell Gate		
Cardigan Strait		
Eastern Arctic: Winter, Spring		
Independent Passage:		
Complex encounters with glacial ice and sea ice (bergy water)		
Baffin Bay		
Simple encounters with icebergs, bergy bits and/or growlers with sea-ice present		
Davis Strait		
Baffin Bay		
Hudson Strait		
Lancaster Sound		
Jones Sound		
Transits of close to very close old or first year pack ice		
Lancaster Sound		
Barrow Strait		
Baffin Bay		
Transits of compact or consolidated old ice or landfast first year ice		
Lancaster Sound		
Barrow Strait		
McDougall Sound		
Baffin Bay		
Hudson Strait		
Hudson Bay		
Fox Basin		
Admiralty Inlet		
Viscount Melville Sound		
Jones Sound		
Wellington Channel		
Norwegian Bay		

Scenarios	Validation	
Eastern Arctic: Winter, Spring	Navigability	Performance
Transits of pressured ice, close to compact concentrations, old or first year		
Lancaster Sound		
Barrow Strait		
Baffin Bay		
Hudson Strait		
Norwegian Bay		
Hell Gate		
Cardigan Strait		
Passage of Conducted Ship during Escort:		
Following in track under conditions of close to very close old or first year pack ice		
Lancaster Sound		
Barrow Strait		
Baffin Bay		
compact, consolidated, or fast old or first year ice		
Lancaster Sound		
Barrow Strait		
McDougall Sound		
Baffin Bay		
Hudson Strait		
Hudson Bay		
Fox Basin		
Admiralty Inlet		
Viscount Melville Sound		
Jones Sound		
Wellington Channel		
Norwegian Bay		
pressured ice, close to compact concentrations, old or first year ice		
Lancaster Sound		
Barrow Strait		
Baffin Bay		
Hudson Strait		
Norwegian Bay		
Hell Gate		
Cardigan Strait		

Scenarios	Validation	
Eastern Arctic: Winter, Spring	Navigability	Performance
Passage of Conducting Ship during Escort:		
Breaking a track under conditions of close to very close old or first year pack ice		
Lancaster Sound		
Barrow Strait		
Baffin Bay		
compact, consolidated, or fast old or first year ice		
Lancaster Sound		
Barrow Strait		
McDougall Sound		
Baffin Bay		
Hudson Strait		
Hudson Bay		
Fox Basin		
Admiralty Inlet		
Viscount Melville Sound		
Jones Sound		
Wellington Channel		
Norwegian Bay		
pressured ice, close to compact concentrations, old or first year ice		
Lancaster Sound		
Barrow Strait		
Baffin Bay		
Hudson Strait		
Norwegian Bay		
Hell Gate		
Cardigan Strait		

Scenarios	Validation	
Eastern Arctic: Winter, Spring	Navigability	Performance
Breaking a tract next to a previously broken track under conditions of:		
compact, consolidated, or fast old or first year ice		
Lancaster Sound		
Barrow Strait		
McDougall Sound		
Baffin Bay		
Hudson Strait		
Hudson Bay		
Fox Basin		
Admiralty Inlet		
Viscount Melville Sound		
Jones Sound		
Wellington Channel		
Norwegian Bay		
pressured ice, close to compact concentrations, old or first year ice		
Lancaster Sound		
Barrow Strait		
Baffin Bay		
Hudson Strait		
Norwegian Bay		
Hell Gate		
Cardigan Strait		

Scenarios	Validation	
Western Arctic: Summer, Fall (Route Specific Operations)	Navigability	Performance
Independent Passage:		
Transits of very open to open old or first year pack ice		
Western Beaufort Sea		
Eastern Beaufort Sea	x	x
Amundsen Gulf/Southern Coastal Route		
Eastern Chukchi Sea		
Transits of close to very close old or first year pack ice		
Western Beaufort Sea		
Eastern Beaufort Sea	x	x
Amundsen Gulf/Southern Coastal Route		
Eastern Chukchi Sea		
Transits of compact or consolidated, old or first year ice		
Western Beaufort Sea		
Eastern Beaufort Sea	x	
Amundsen Gulf/Southern Coastal Route		
Eastern Chukchi Sea		
Transits of pressured ice, close to compact concentrations, old or first year		
Western Beaufort Sea		
Eastern Beaufort Sea		
Eastern Chukchi Sea		
Passage of Conducted Ship during Escort:		
Following an icebreaker under conditions of: open old or first year pack ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Amundsen Gulf/Southern Coastal Route		
Eastern Chukchi Sea		
Following in track under conditions of: close to very close old or first year pack ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Amundsen Gulf/Southern Coastal Route		
Eastern Chukchi Sea		

Scenarios	Validation	
Western Arctic: Summer, Fall (Route Specific Operations)	Navigability	Performance
compact or consolidated, old or first year ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Amundsen Gulf/Southern Coastal Route		
Eastern Chukchi Sea		
pressured ice, close to compact concentrations, old or first year ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Eastern Chukchi Sea		
Passage of Conducting Ship during Escort:		
Escort operations in open old or first year pack ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Amundsen Gulf/Southern Coastal Route		
Eastern Chukchi Sea		
Breaking a track under conditions of: close to very close old or first year pack ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Amundsen Gulf/Southern Coastal Route		
Eastern Chukchi Sea		
compact or consolidated, old or first year ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Amundsen Gulf/Southern Coastal Route		
Eastern Chukchi Sea		
pressured ice, close to compact concentrations, old or first year ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Eastern Chukchi Sea		

Scenarios	Validation	
Western Arctic: Summer, Fall (Route Specific Operations)	Navigability	Performance
Breaking a tract next to a previously broken track under conditions of:		
compact or consolidated, old or first year ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Amundsen Gulf/Southern Coastal Route		
Eastern Chukchi Sea		
pressured ice, close to compact concentrations, old or first year ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Eastern Chukchi Sea		
Western Arctic: Winter, Spring (Route Specific Operations)		
Independent Passage:		
Transits of close to very close old or first year pack ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Eastern Chukchi Sea		
Transits of compact or consolidated old ice or landfast first year ice		
Western Beaufort Sea		
Eastern Beaufort Sea	x	x
Amundsen Gulf/Southern Coastal Route		
Eastern Chukchi Sea		x
Transits of pressured ice, close to compact concentrations, old or first year		
Western Beaufort Sea		
Eastern Beaufort Sea		
Eastern Chukchi Sea		x

Scenarios	Validation	
Western Arctic: Winter, Spring (Route Specific Operations)	Navigability	Performance
Passage of Conducted Ship during Escort:		
Following in track under conditions of: close to very close old or first year pack ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Eastern Chukchi Sea		
compact or consolidated old ice or landfast first year ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Amundsen Gulf/Southern Coastal Route		
Eastern Chukchi Sea		
pressured ice, close to compact concentrations, old or first year ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Eastern Chukchi Sea		
Passage of Conducting Ship during Escort:		
Breaking a track under conditions of: close to very close old or first year pack ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Eastern Chukchi Sea		
compact or consolidated old ice or landfast first year ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Amundsen Gulf/Southern Coastal Route		
Eastern Chukchi Sea		
pressured ice, close to compact concentrations, old or first year ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Eastern Chukchi Sea		

Scenarios	Validation	
	Navigability	Performance
Western Arctic: Winter, Spring (Route Specific Operations)		
Breaking a tract next to a previously broken track under conditions of:		
compact or consolidated old ice or landfast first year ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Amundsen Gulf/Southern Coastal Route		
Eastern Chukchi Sea		
pressured ice, close to compact concentrations, old or first year ice		
Western Beaufort Sea		
Eastern Beaufort Sea		
Eastern Chukchi Sea		
Western Arctic: Spring (Site Specific Operations)		
Ice management during break-up, in support of site specific drilling operations:		
Close tactical defense slightly updrift		
Tactical defense some distance updrift		
Reconnaissance at greater range from drill-site		
Other operations:		
Anchor handling (deployment, retrieval)		
Re-supply		
Fire-fighting		
Personnel transfer		
Helicopter support		
Western Arctic: Summer (Site Specific Operations)		
Ice management during open water period, in support of site specific drilling operations:		
Close tactical defense slightly updrift		
Tactical defense some distance updrift		
Reconnaissance at greater range from drill-site		
Other operations:		
Anchor handling (deployment, retrieval)		
Re-supply		
Fire-fighting		
Personnel transfer		
Helicopter support		

Scenarios	Validation	
Western Arctic: Fall, Winter (Site Specific Operations)	Navigability	Performance
Ice management during freeze-up, in support of site specific drilling operations:		
Close tactical defense slightly updrift	x	x
Tactical defense some distance updrift	x	x
Reconnaissance at greater range from drill-site		
Other operations:		
Anchor handling (deployment, retrieval)		
Re-supply	x	x
Fire-fighting		
Personnel transfer	x	x
Helicopter support		x

Western Arctic: Winter (Site Specific Operations)

There are no relevant site specific marine or ship-related operations that take place at this time of the year other than dedicated ship trials.

Appendix C

COMPUTER-TIMED TASK ANALYSIS

The task analysis technique described and used up to this point is based on the time sampling at 15-second intervals of up to six bridge crew member's positions and activities. This technique gains in breadth of coverage at the expense of precision in timing, because the unit of time measurement is coarse relative to the duration of some of the activities sampled. An alternative task analysis technique was developed to sample one crew members's position and activities at a continuous rate. It uses direct input of codes signalling changes of position and activity to a hand-held computer (Radio Shack PC2). The computer's real-time clock assigns a time to the entry of the code, stores the sequence of codes and times, and either prints them or transfers them to magnetic tape for further processing.

The microcomputer was used to collect data on both the fall 1984 and spring 1985 voyages of Kigoriak, along with conventional task analysis techniques. A total of thirteen sessions of computer task analysis data was recorded in the fall of 1984, and twelve sessions were recorded in the spring of 1985. The sessions ranged from 15 min to two hours in length.

This technique allows specification of the distribution of intervals between successive activities. The statistical parameters of this distribution, particularly its mode and median, are one definition of the workload imposed on the operator.

Method

Observation Technique

The observer was equipped with a Radio Shack PC2 pocket sized microcomputer which has a real time clock. The PC2 was programmed to record codes entered through the keyboard, up to 5 alphameric characters in length, and store each code in a file along with the time (to the nearest second) at which the code was entered. At night the observer carried a red-filtered light, attached to a clipboard, to illuminate the keyboard.

The observer stood approximately 3 metres from the operator in a position that gave a clear view of the consoles and the operator's hands when he was operating the ship controls.

Variables Recorded

At the beginning of each episode the exact time in GMT and local time were entered, along with the name of the operator, the current position of the ship in latitude and longitude, the weather conditions and ice conditions. During the episode the observer entered codes recording the adjustments to course, and speed; the operation of thrusters; use of radar, binoculars, searchlights, and communications equipment, and movements from

one operating position to another. During the spring voyage of the Kigoriak the set of codes was enlarged to record changes of gaze from one quadrant to another (forward, aft, port and starboard).

During ice defense operations a second officer frequently assisted the operator by postioning the searchlights and dealing with communications. These events were also recorded.

Data Analysis

The data for the fall and spring voyages were entered into SPSS-X files in a format in which each case contained the data describing the episode in which the observations were recorded, along with the activity code and its associated time. This file structure made it possible to sort activity codes and inter-activity intervals according to the codes describing the episode (e.g. by time of day, type of activity etc).

Inter-activity intervals and their distributions were computed for all activities together, and for different activities separately, to describe the work load. The activity classes used were Observations (visual and radar), Communications, Course Changes, Speed Changes and Movements (to different consoles or the chart table).

Transition matrices were computed for 2 and 3 activity sequences.

Results

Workload

Thirteeen episodes were recorded during the fall of 1984 and 12 episodes were recorded during the spring of 1985. Episodes ranged from 15 minutes to 2 hours in length.

The distributions of inter-activity times for all activities together for the fall and spring voyages are shown in Figure 1. The data show that on Kigoriak the operator is almost continuously active during ice mangement operations. More than 20% of activities began within 10 sec of the start of the previous activity and less than 25% of the interactivty times were longer than 60 seconds. As might be expected the work load , as shown by the mean and median inter-activity intervals, was greater during night operations when the operation of searchlights was added to the task. It was also greater during the fall than in the spring. This is probably because in the fall, ice management involved breaking up large floes, often close to the drill ship, while in the spring the Kigoriak was operating alone in a unbroken ice field.

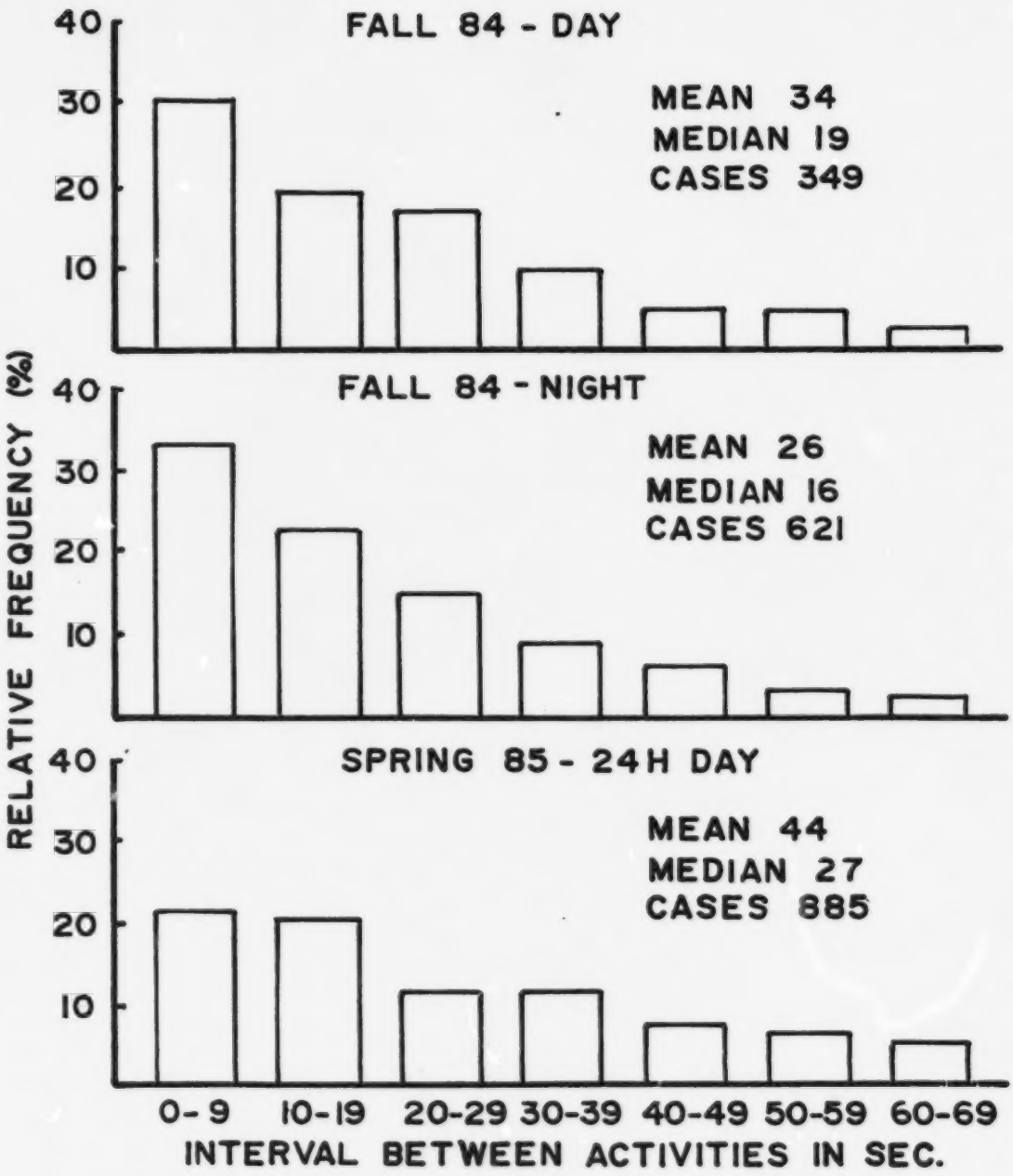

Figure 1 Distribution of the intervals between successive activities executed by the operator on the bridge of Kigoriak. Samples taken in fall 1984 and spring 1985.

Table 1 Frequency of occurrence of different types of activity expressed as a percentage of total activity for activities recorded during day and night operations in fall 1984, and in continuous day in spring 1985.

Activity	Fall - Day	Fall - Night	Spring
Communications	1.7	1.5	7.5
Radar *	4.6	18.2	0.9
Course adjustment	69.8	48.3	9.4
Speed adjustment	12.9	7.7	60.4
Search light adjust	- -	11.6	- -
Search light adjust (2nd officer)		5.8	
Change of position	< .1	< .1	9.6

* Note Radar use does not include the daylight radar or the mini-ranger which were added to Kigoriak's navigating equipment in the spring.

Table 2 Mean and median intervals, in seconds, between successive occurrences of the same activity.

Activity	Fall - Day		Fall - Night		Spring	
	Mean	Med.	Mean	Med.	Mean	Med.
Radar	182	83	122	59	**	**
Course adjustment	45	20	46	28	126	38
Speed adjustment	138	44	197	35	66	38
Search lights			155	40		
Search lights (2nd Officer)			161	43		
Change of position	**	**	**	**	278	113

** Too few occurences to compute intervals.

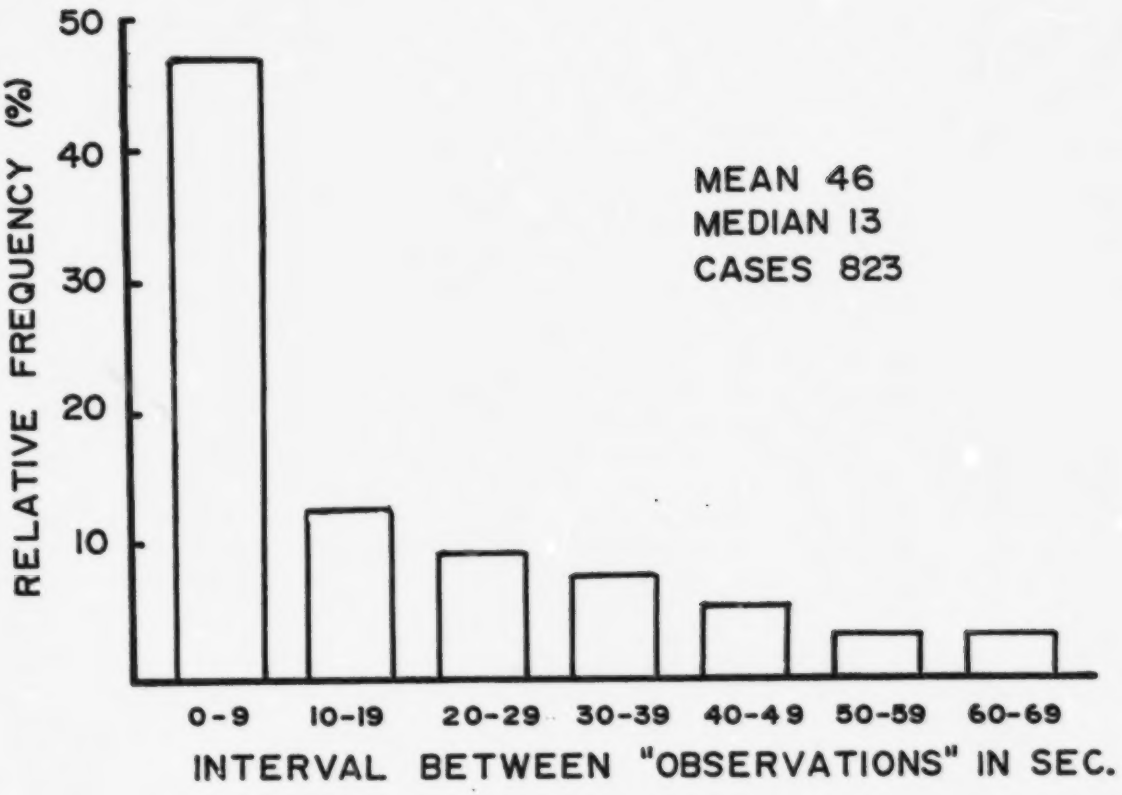

Figure 2 Distribution of the intervals between successive observations made by the operator of Kigoriak as defined by changes in the direction of gaze.

Distribution of Workload Amongst Different Activities

The different operating conditions in the fall and spring affected the way operators distributed their time amongst different activities. Table 1 shows the relative frequency with which operators used communications or radar equipment, made adjustments to course speed or searchlights, and changed position on the bridge. Table 2 shows the mean and median intervals between successive occurences of the same activity.

It can be seen from Table 1 that in the fall more than 50% of acts were course adjustments and at night nearly 30% of the acts involved the use of searchlights and radar. This distribution of effort is consistent with the operator's task which involved locating and ramming ridges and floes of second year ice, often in the vicinity of other vessels. In addition to avoiding collisions, radar was used to maintain the ship's icebreaking course on a line directly up-drift from the drill ship. The use of radar for positioning was important both night and day. The importance of the searchlights for icebreaking at night is confirmed by the fact that more than 11% of the operator's acts were to adjust the position of the lights and a additional 6% of the acts recorded were changes of searchlight position carried out by another officer.

It should be noted that the data in Table 1 are not directly comparable to those in Table 3.2 and Table 3.3 of the report. For example Communications might appear to be less frequent from Table 1 than from Table 3.3. This comparison is not exact because of the different ways the data was collected. The data in Tables 3.2 and 3.3 show the percentage of sampling intervals in which a particular activity was noted while the data in Table 1 show the number of times a given activity was initiated. Thus an activity that extends through several sampling intervals would be recorded more than once in Table 3.2 or table 3.3. but only once in Table 1.

During the spring the most frequent act was to adjust the speed. This category of activity included both changes to speed and shifts of thrust from forward to astern, or vice versa. The predominance of speed adjustments reflects the fact that, in the spring, most of the time was spent breaking tracks. This task involves backing and ramming and therefore frequent thrust reversals. The frequent backing is also reflected in the higher frequency of changes of position. The operator frequently moved to the aft console when backing up a narrow track, and then returned to the forward console as soon as the ship began to move forward.

For the episodes recorded in the spring, codes representing the driver's direction of gaze within a quadrant (forward, aft, port, starboard) were added to the data set and are summarized in Table 3 (Tables 3 through 8 are shown at the end of this appendix). The most frequent transitions were from looking forward to looking aft and from looking aft to looking forward. This pattern of activity is necessitated by the relatively light armour on the after quarters of Kigoriak and the risk of damaging the rudders by backing them into heavy ice. These data underline the importance of good visibility

aft for ships operating in heavy ice (see also Donderi and Ostry 1985, Report No TP5623E).

The distribution of the intervals between successive changes in gaze are shown in Figure 2. Changes of gaze occurred every few seconds and 50% of shifts of gaze were separated by less than 13 seconds. Only 10% of observations were longer than 90 seconds.

Transitions Between Different Activities

Tables 4, 5, and 6 show the first order transition matrices for the major categories of activities recorded in the fall at night, in the fall night and day together excluding searchlight operation, and in the spring, respectively. Tables 8 and 9 show second order transition matrices for the most frequently recorded activities. Because the number of cells in a transition matrix increases with the square of the number of activities counted and the power of the number of activities in a sequence, very large numbers of observations are needed to compute matrices with non-empty cells for more than a few activities and for sequences longer than three activities. There were not enough observations to compute a separate first order transition matrix for activities recorded during daylight in the fall, or to include the more infrequent activities such as radar use. For the same reason only a few of the possible second order matrices could be computed.

The matrix of each set shows the observed frequency of transitions and the second set the probability of transitions. The Chi Square statistics for both first and second order matrices showed that transitions were significantly non-random in all cases ($p < .001$). The cells representing repetitions of a single activity contained more observations than to be expected by chance. This indicates that activities tend to be repeated two or three times in succession before another activity is begun. This pattern is consistent with the nature of the driver's task which can be conceived of as a set of tracking tasks i.e. controlling speed, heading etc. In such tasks adjustments tend to be made in a series in which an initial response is followed by a series of corrections which bring the appropriate indicator on target. The same pattern is to be expected from visual observations and communications. Changes of gaze would be expected to involve a sweep through several quadrants before returning to forward gaze. Communications usually involve an initial call or response to a call followed by several exchanges.

When activity sequences comprised of repetitions of a single activity were removed from the first order transition matrices the residual matrices were still significantly non-random. The most frequent transitions were from course adjustment to speed adjustment and vice versa. Course adjustments were also frequently preceded, or followed, by visual observation. During the hours of darkness in the fall, use of the searchlights was associated with course adjustments, in fact 43% of adjustments to the searchlights were followed by a course adjustment. Moreover 10% of all course adjustments were preceded by adjustments to the search lights. These data emphasize again the importance of searchlights for icebreaking at night. Further, these data

agree with the results of the conventional task analysis, presented in the main body of this report, showing that the activity sequences are not random. There are at least first order dependencies present. A larger data set would be needed to test second order trends.

Summary and Conclusions

The operator engaged in ice management, on a single operator ship like Kigoriak, is almost continuously active in conning the ship and makes frequent use of all the major controls. Each of the major controls is adjusted several times in series before the operator moves on to another task. The ordering of tasks in sequence is not random. Adjustments to course and speed tend to occur together. Course adjustments are linked to visual observations and, at night, to the use of searchlights.

Recording task analysis data with a portable microcomputer was found to be a useful adjunct to conventional task analysis for the purpose of obtaining estimates of workload and establishing sequential dependencies between different activities. Experience with the use of a microcomputer shows that it would be possible to record a larger set of activities than was used in this inital trial.

To analyse sequential dependencies a very large data set is required. From the experience gained in this exploratory trial it would be advantageous to use a microcomputer with a larger memory and with the capability to transfer data to a mass storage device such as a disc drive. Portable machines with these characteristics are now readily available.

TABLE 3
KIGORIAK SPRING 85: GAZE SEQUENCE ANALYSIS

FIRST ORDER TRANSITION FREQUENCY MATRIX 840 OBSERVATIONS

	FWD	SBD	PRT	AFT
FWD	36	61	145	146
SBD	64	4	4	9
PRT	136	5	6	20
AFT	153	11	15	25

FIRST ORDER TRANSITION PROBABILITY MATRIX

FWD	.04	.07	.17	.17
SBD	.08	.00	.00	.01
PRT	.16	.01	.01	.02
AFT	.18	.01	.02	.03

TEST FOR ZERO- VERSUS FIRST-ORDER DEPENDENCY

CHI-SQUARE STATISTIC (9 D.F.): 456.364

TABLE 4
KIGORIAK FALL 84: DAYTIME ACTIVITY SEQUENCE ANALYSIS

FIRST ORDER TRANSITION FREQUENCY MATRIX 348 OBSERVATIONS

	OBS	COM	SPD	CRS
OBS	15	2	1	16
COM	2	2	2	3
SPD	1	2	21	25
CRS	16	3	25	212

FIRST ORDER TRANSITION PROBABILITY MATRIX

OBS	.04	.01	.00	.05
COM	.01	.01	.01	.01
SPD	.00	.01	.06	.07
CRS	.05	.01	.07	.61

TEST FOR ZERO- VERSUS FIRST-ORDER DEPENDENCY

CHI-SQUARE STATISTIC (9 D.F.): 97.9853

TABLE 5
KIGORIAK FALL 84: NIGHT-TIME ACTIVITY SEQUENCE ANALYSIS

FIRST ORDER TRANSITION FREQUENCY MATRIX 621 OBSERVATIONS

	OBS	COM	SPD	CRS	LTS
OBS	27	1	6	77	15
COM	3	4	1	6	2
SPD	7	0	25	24	1
CRS	81	10	20	197	34
LTS	9	1	5	38	26

FIRST ORDER TRANSITION PROBABILITY MATRIX

OBS	.04	.00	.01	.12	.03
COM	.00	.01	.00	.01	.00
SPD	.01	.00	.04	.04	.00
CRS	.13	.02	.03	.32	.05
LTS	.01	.00	.01	.06	.04

TEST FOR ZERO- VERSUS FIRST-ORDER DEPENDENCY

CHI-SQUARE STATISTIC (16 D.F.): 275.175

TABLE 6
KIGORIAK SPRING 85: ACTIVITY SEQUENCE ANALYSIS

FIRST ORDER TRANSITION FREQUENCY MATRIX 1761 OBSERVATIONS

	OBS	COM	SPD	CRS	MVS
OBS	589	39	186	23	51
COM	47	33	31	7	5
SPD	181	33	308	7	30
CRS	21	5	11	46	4
MVS	50	13	22	4	15

FIRST ORDER TRANSITION PROBABILITY MATRIX

OBS	.33	.02	.11	.01	.03
COM	.03	.02	.02	.00	.00
SPD	.10	.02	.17	.00	.02
CRS	.01	.00	.01	.03	.00
MVS	.03	.01	.01	.00	.01

TEST FOR ZERO- VERSUS FIRST-ORDER DEPENDENCY

CHI-SQUARE STATISTIC (16 D.F.): 795.488

TABLE 7
KIGORIAK FALL 84: ACTIVITY SEQUENCE ANALYSIS

SECOND ORDER TRANSITION FREQUENCY MATRIX 865 OBSERVATIONS

	OBS	SPD	CRS
OBS	22	0	34
SPD	0	4	2
CRS	27	4	68
OBS	1	3	5
SPD	3	24	18
CRS	3	20	29
OBS	26	4	67
SPD	5	19	31
CRS	74	28	344

SECOND ORDER TRANSITION PROBABILITY MATRIX

OBS	.03	.00	.04
SPD	.00	.00	.00
CRS	.03	.00	.08
OBS	.00	.00	.01
SPD	.00	.03	.02
CRS	.00	.02	.03
OBS	.03	.00	.08
SPD	.01	.02	.04
CRS	.09	.03	.40

TEST FOR FIRST- VERSUS SECOND-ORDER DEPENDENCY

CHI-SQUARE STATISTIC (12 D.F.): 114.5

TABLE 8
KIGORIAK SPRING 85: ACTIVITY SEQUENCE ANALYSIS

SECOND ORDER TRANSITION FREQUENCY MATRIX 1532 OBSERVATIONS

	OBS	SPD	CRS
OBS	478	124	13
SPD	158	86	1
CRS	13	4	11
OBS	155	84	2
SPD	55	239	5
CRS	4	8	5
OBS	16	6	10
SPD	1	6	6
CRS	8	0	34

SECOND ORDER TRANSITION PROBABILITY MATRIX

OBS	.31	.08	.01
SPD	.10	.06	.00
CRS	.01	.00	.01
OBS	.10	.05	.00
SPD	.04	.16	.00
CRS	.00	.01	.00
OBS	.01	.00	.01
SPD	.00	.00	.00
CRS	.01	.00	.02

TEST FOR FIRST- VERSUS SECOND-ORDER DEPENDENCY

CHI-SQUARE STATISTIC (12 D.F.)= 173.194

Appendix D

INFORMATION SOURCES FOR NAVIGATION DECISIONS

Strategic and tactical Arctic navigation decisions rely on a variety of sources of information. In this Section we describe the available sources and the characteristics of the information that are important to the operator. We describe the information available in both the eastern and western Arctic. A quantitative evaluation of the use of radar, binoculars and night vision aids as a function of ice conditions and visibility is presented. The information available from ship-mounted radar, visual observation and SAR displays as well as needed improvements to these systems are discussed.

Information Sources in Eastern and Western Arctic

Information for strategic, tactical, and close tactical decisions in Arctic navigation comes from a variety of sources. Sources differ in the eastern and western Arctic. Different sources of information are available at different points in a voyage. Some types of information are available on a routine basis while other types, such as from helicopter reconnaissance, SAR, and satellite imagery are available only when specific arrangements can be made.

Ice and weather information that is received on key (long wave) and in the form of facsimile maps is generally available in the Arctic and normally well accepted by mariners. This information is useful for strategic planning. But it is not timely enough to be helpful as an aid to tactical or close tactical decision making. More timely information is available from visual observation, binoculars, ship-mounted and airborne radar and electronic image intensifiers. However, preference for and reliance upon the various radars and night vision aids differs greatly among Masters.

The sources of information in the eastern and western Arctic are listed below:

Eastern Arctic Strategic Information Sources:

- ice facsimile reports from Canada and Greenland
- weather facsimile reports from Canada and England
- ice edge reports on key (long wave) from Coast Guard
- weather reports on key (long wave)
- ice condition reports on key (long wave)
- interpretted satellite imagery reports by telex
- satellite communications systems
- HF voice communications

- SAR transparencies
- SLAR transparencies

Eastern Arctic Tactical Information Sources:

- SAR transparencies
- SLAR transparencies
- VHF voice communications
- helicopter reconnaissance provided by Coast Guard icebreakers
- reports from shore installations

Eastern Arctic Close Tactical Information Sources:

- marine radar
- electronic image intensifiers
- visual observation aided by binocular use

Western Arctic Strategic Information Sources:

- instructions from Calgary (or Ottawa)

Western Arctic Tactical Information Sources:

- photographic SAR (Star 1)
- interpretted SAR from Tuktoyuktuk
- weather facsimile reports from AES
- ice facsimile reports from AES
- helicopter reconnaissance by the operator
- VHF communications from other ships

Western Arctic Close Tactical Information Sources:

- marine radar
- electronic image intensifiers
- visual observation aided by binoculars
- microwave positioning systems
- ice drift reports hourly or half hourly

Distribution of Use of Radar, Binoculars, Night Vision Aids

The distribution of the use of radar, binoculars and night vision aids was evaluated on the M.S. Thuleland during the passage to and from Polaris in September 1984 and on the M.V. Canmar Kigoriak during late season ice defense in November 1984. The aim was to establish in a systematic manner the relationship between the visibility and ice conditions in the Arctic and the use and distribution of ice observation aids.

Apart form individual preferences, the frequency of use of various ice observation aids depends on the particular task at hand, the range of information sources and observation aids that can be used for the task, the number and locaton of pieces of relevant equipment on the bridge, the ice conditions, visibility and the ambient light level.

On the Thuleland, aids to tactical decision making include 3 and 10 cm radar, a Varo Noctron Night Vision System (Model 9878) and binoculars. During the September 1984 passage of the Thuleland there were encounters with glacial ice in Davis Strait and Baffin Bay and encounters with trace quantities of old ice and/or thick first year ice and encounters with a limited number of open to very open strips and belts of mostly old ice in Lancaster Sound and Barrow Strait.

On Kigoriak, only 3 cm radar and binoculars were available. The ice conditions in the fall of 1984 ranged from 2 to 6/10 gray, gray white ice and 2 to 7/10 old ice in close pack to compact pack concentrations.

The distribution of equipment use was established by recording the frequency with which each of the bridge crew used the ice observation aids described above. The recording sessions were one hour in duration in order to correspond with the recording interval for navigability data.

On the Thuleland, equipment use was recorded on nine separate occasions. On the Kigoriak, 13 sessions were recorded. The environmental conditions at the time of recordings are shown in Tables 1 and 2.

In Figures 1 and 2 the average frequency of equipment use per minute is shown for the Thuleland as a function of the ice cover and illumination level, respectively. In Figure 1 the frequency of equipment use per minute is plotted for bergy water and trace quantities of old ice. The pattern for the radars and the night vision system is similar; their use increases in bergy water as compared with their use with trace quantities of old ice. Binoculars, on the other hand, are used more frequently in the old ice conditions. Binoculars were used both in daylight and at night. Some of the bridge crew on the Thuleland preferred the binoculars to the night vision system because the binoculars did not degrade scene resolution or their night vision.

The frequency of use of ice observation aids on the Thuleland was high. Even when there were only trace quantities of old ice, binoculars were used on average 1.52 times per minute. Thus, on the Thuleland, there is considerable reliance on binoculars for the visual identification of ice.

Figure 2 shows the frequency of use on the Thuleland of binoculars, radar and the night vision system in daylight, moderate and deep twilight conditions. The Figure indicates that the use of radar and the night vision system both increase as ambient illumination decreases. Binocular use, on the other hand, is highest during daylight hours and decreases at night.

In Figures 3, 4 and 5 the average frequency of equipment use per minute is shown for the Kigoriak as a function of the ice cover, illumination level and visibility, respectively. In Figure 3 the frequency of equipment use per minute is shown as a function of the ice cover. The use of binoculars is infrequent and is unrelated to differences in cover. In contrast, radar use is least in previously worked areas and increases as the ice cover approaches compact pack.

The distribution of equipment use is shown in Figure 4 as a function of illumination level. Radar use is low during daylight hours and much higher at lower light levels. Binoculars are used infrequently.

A systematic relationship between the distribution of equipment use and visibility is seen in Figure 5 in which the frequency of use is shown as a funcion of visibility in sea miles. The main finding is that radar use is frequent for visibilities of less than eight miles and occurs very infrequently when visibility is greater.

Overall, the frequency of use of ice observation aids was greater on the Thuleland than on the Kigoriak. This was primarily the result of differences in binocular use. Binoculars were used frequently on the Thuleland and rarely on the Kigoriak. Binoculars are presumably more important for transiting ships.

Information from Visual Observation

Visual observation, often aided by binoculars, is the most frequently used technique for obtaining ice information during a normal Arctic voyage. Visual observation provides information on ice type, concentration, freeboard, surface deformation, leads and open water.

No systematic studies of ice detection performance have been carried out. Consequently, our knowledge of human operator abilities in this area is based largely on the intuitions of skilled ice observers. This provides a first approximation to human performance limits. However, without systematic assessment, not only of correct detections, but also of misses and false positives, it is not clear how much of visual ice detection performance is due to operator sensitivity and how much to educated guessing.

The consensus on visual ice detection and identification performance is as follows. At distances beyond 10 km, only large scale features of the ice cover can be detected visually. This includes leads, open water patches and icebergs. Detection performance improves with binoculars.

At shorter distances, more information on ice type, concentration, freeboard and surface deformation is available. Freeboard differences tend

to be detectable at about the same distance as surface deformation and floe size. The detection of freeboard differences becomes increasingly difficult as concentration exceeds 6 or 7/10. Ice type is determined visually on the basis of surface contour, freeboard, and to a lesser extent colour. Unaided visual identification of old ice is typically possible at distances of 1 km or less. With binoculars, old ice can be detected at distances of up to 2 - 3 km. Fog, snow and darkness reduce visual ice detection performance.

The ice abaft of the ship provides information on ice thickness and ice type. Pressure in the ice field is revealed by the rate at which the ship's track closes. The aft view also provides information on ice thickness.

Information from Ship's Radar

Ship's radar is a major source of information on the characteristics of the ice cover. X-band radar is sensitive to ice textural differences produced by surface deformation, icebergs and smaller pieces of glacial ice, leads and open water. X-band radar is also capable of distinguishing first year ice and old ice. However, in a monochrome radar display, the brightness differences between old and first year ice are generally insufficient to reliably distinguish the ice types.

A frequent complaint among radar users is that radar information is ambiguous. For example, the absence of a return may signal either a uniform ice sheet, open water or open water leads. Furthermore, small targets such as growlers can be readily lost in the sea-clutter.

There are several ways that ship's radar displays could be improved to enhance ice detection performance. Incoherent averaging, such as used in SAR, would reduce clutter and improve gray-scale resolution. There would be some reduction in spatial resolution as a result. Averaging would also necessitate a reduction in the frequency with which the radar screen was updated, from once each cycle of the antenna to once every three, four, or perhaps five cycles.

An alternate technique, currently available on the radars of the USCGC Polar Sea is to stream the radar return by intensity. Returns that are greater than a specifiable intensity are amplified and returns below this cutoff are attenuated. This produces a decrease in background noise without reducing the radar update rate.

A further alternative that should be field tested in the Canadian Arctic is the use of false-colour displays for ship's radar. In false-colour displays, colour is mapped to the signal intensity continuum, often with the choice of colour steps selected by the operator. Old ice and first year ice have radar returns whose amplitudes are sufficiently different that false-colouring should enable the operator to readily identify old ice in the radar display. If false colouring were supplemented by some form of signal averaging the distinction between old and first year ice could be particularly clear.

Information from SAR Displays

Airborne synthetic aperature radar (SAR) is the most promising remote sensing technique at the present time. It is preferred because of its coverage, resolution, timeliness and the clear distinction it provides between first-year and old ice.

In the eastern Arctic, SAR is transmitted in real-time to ships such as the M.V. Arctic that are equipped with downlink receivers. The imagery is currently available in the form of transparancies, however, a video display system for SAR imagery is soon to be tested on the Arctic. In the western Arctic, SAR is transmitted to a ground station for photographic processing and is then taken to ships of the Canmar and BeauDril fleets by helicopter.

The radar parameters for SAR are effectively optimized in the STAR-1 system operated by Intera Technologies of Calgary. The performance of the CCRS/ERIM SAR-580 is comparable. The STAR-1 system is a light-weight X-band HH-polarized radar that is filtered using 7-look incoherent averaging. The averaging process reduces the spatial resolution of the image somewhat but improves its gray-scale resolution. Operators feel that the reduction in speckle more than compensates for the loss in spatial resolution.

The microwave signatures of first year ice and old ice are distinct. This enables the ice observer to readily distinguish the differences between old and first year ice on the SAR display. The difference in microwave returns between first year ice and old ice is reduced during the summer melt. There is insufficient experience with the use of the STAR-1 system during the melt to assess its performance under these conditions.

The major problem with SAR imagery is that high bandwith / high resolution transmission systems are expensive. Efforts are now underway to develop low bandwith transmission lines to promote the wider use of SAR imagery. However, if bandwith reduction schemes ar to be effective human engineering assessments of the required spatial and gray-scale resolution of the SAR image should be conducted.

Table 1 Environmental Conditions during Ice Observation Episodes
M.S. Thuleland, September 1984

		Frequency of Use per Minute				
Date	Local Time	Binoc	Radar	Night Vis	Ice Cover	Visibility
840995	21:00	1.32	1.46	0.05	trace old ice	4-6 mi moderate twilight
840906	07:00	2.22	0.28	0.00	strips old ice	10-12 mi daylight
840908	13:00	2.00	0.27	0.00	very open pack old ice	10-12 mi daylight
840908	14:00	1.34	0.20	0.00	very open pack old ice	12-15 mi daylight
840908	15:00	0.30	0.13	0.00	trace old ice	12-15 mi daylight
840908	22:00	1.93	1.35	0.73	trace old ice	10-12 mi moderate twilight
840909	00:00	1.78	1.27	0.45	bergy water; trace old ice	4-6 mi deep twilight
840909	23:00	0.40	0.80	0.47	bergy water	6-8 mi deep twilight
840910	21:00	0.68	1.30	0.75	bergy water	4-6 mi deep twilight

Table 2 Environmental Conditions during Ice Observation Episodes
M.V. Canmar Kigoriak

Date	Local Time	Ice Cover	Visibility	Activity
841017	16:00	close to very close pack 2/10 gray/gray white 6-7/10 old ice	12-15 mi daylight	ice management
841017	22:00	open to close pack 3/10 gray/gray white 4-5/10 old ice	3-4 mi darkness	ice management
841018	00:00	close pack 2/10 gray/gray white 5-6/10 old ice	3-4 mi darkness	ice management backing and ramming
841018	20:00	close to very close pack 4/10 gray/gray white 4-5/10 old ice	4-5 mi moderate twilight	ice management
841018	21:00	very close to compact pack 4/10 gray/gray white 5/10 old ice	2-3 mi deep twili ght	ice management prior to pulling anchors
841019	00:00	already worked area gray/gray white old ice, brash size pieces, compact	1-2 mi darkness	ice management during disconnect
841019	11:00	close to very close pack 2/10 gray/gray white 6-7/10 old ice	6-8 mi daylight	Kigoriak moving to well site to act as marker
841021	09:00	already worked area close pack mostly brash ice	3-4 mi deep twilight	ice management
841021	10:00	already worked area close pack mostly brash ice	4-5 mi moderate twilight	close in ice management with Explorer III on location
841021	11:00	ice as above	6-8 mi daylight	close in ice management Kigoriak stopped

Table 2 Environmental Conditions during Ice Observation Episodes M.V. Canmar Kigoriak, October 1984 (con't)

Date	Local Time	Ice Cover	Visibility	Activity
841021	12:00	very close to compact pack 6/10 gray/gray white 3-4/10 old ice	4-6 mi daylight	ice management updrift
841021	19:00	ice as above	6-8 mi daylight	ice management updrift
841022	21:00	very close to compact pack 6-7/10 gray/gray white 3/10 old ice	2-3 mi darkness	stopped updrift

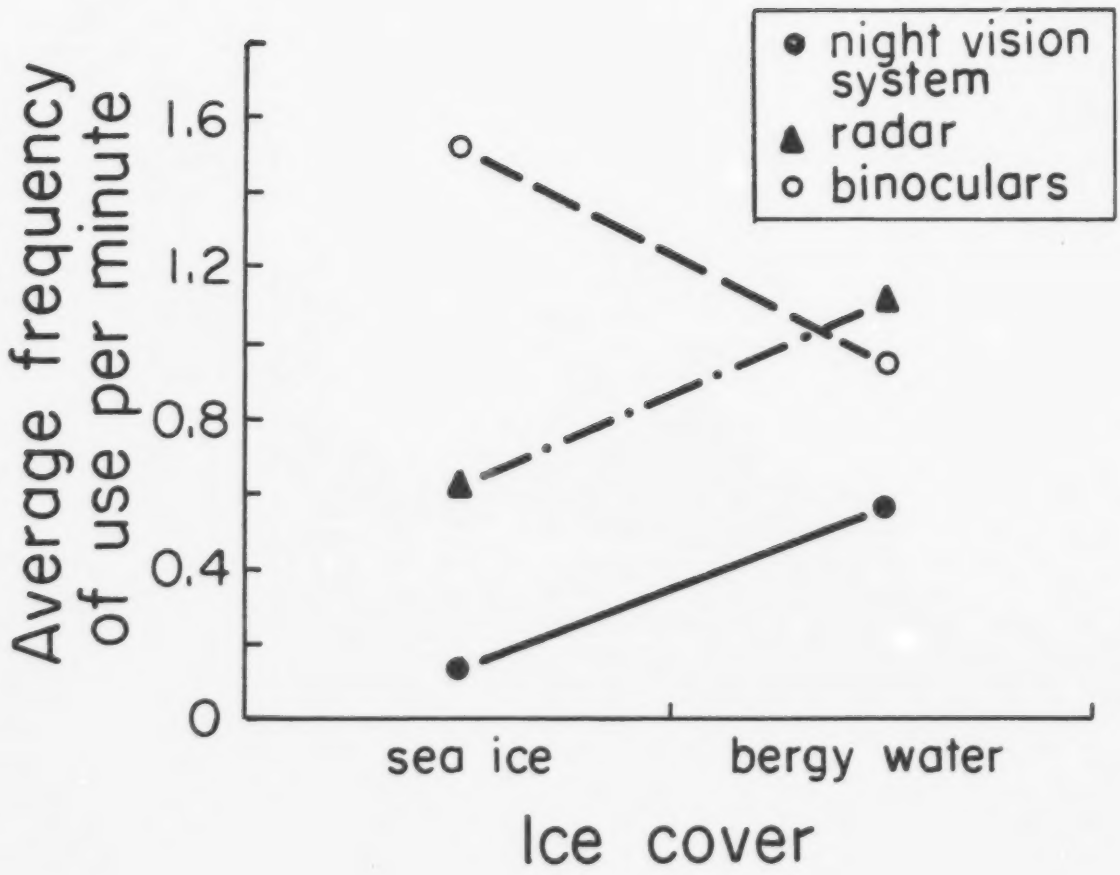

Figure 1 Average frequency of use of radar, binoculars and night vision aids as a function of ice cover, M.S. Thuleland, September 1984

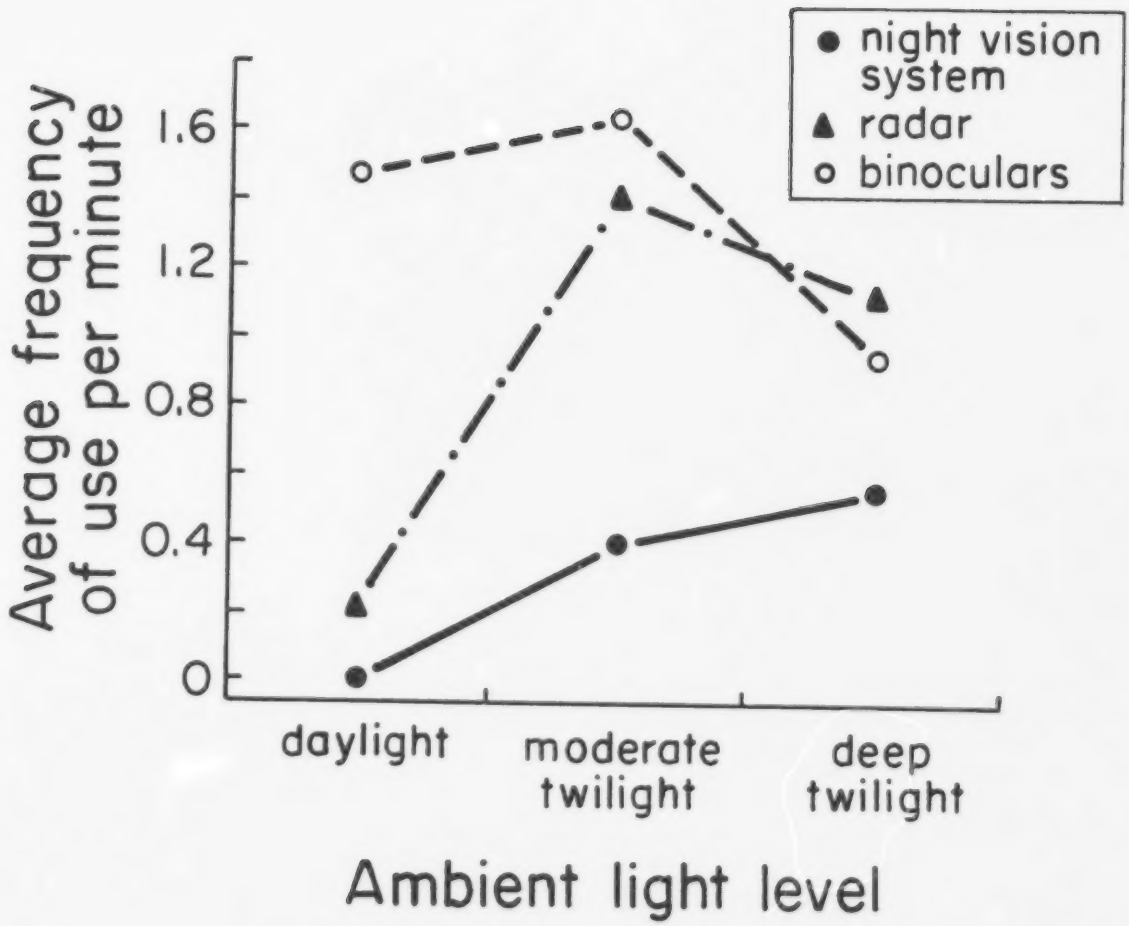

Figure 2 Average frequency of use of radar, binoculars and night vision aids as a function of ambient light level, M.S. Thuleland, September 1984

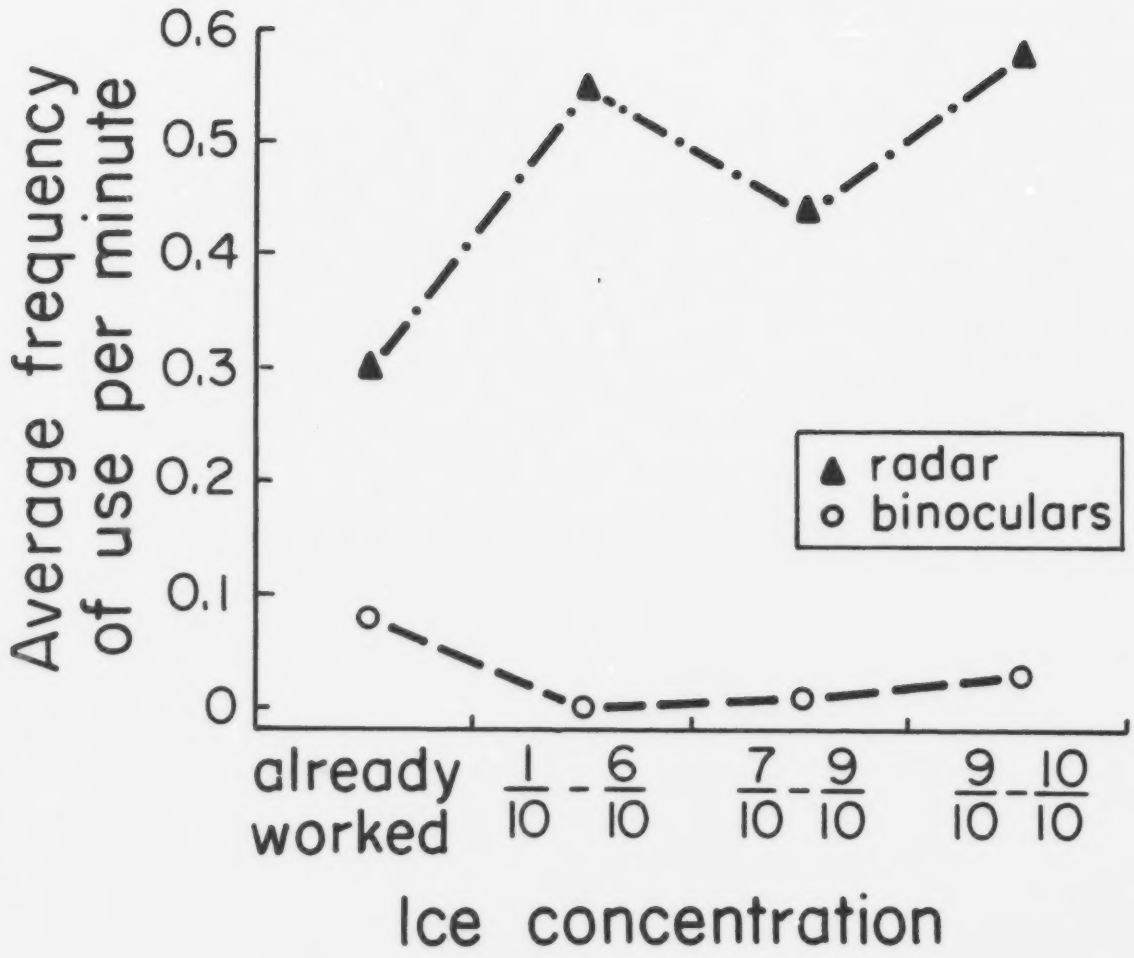

Figure 3 Average frequency of use of radar and binoculars as a function of ice cover, M.V. Canmar Kigoriak, October 1984

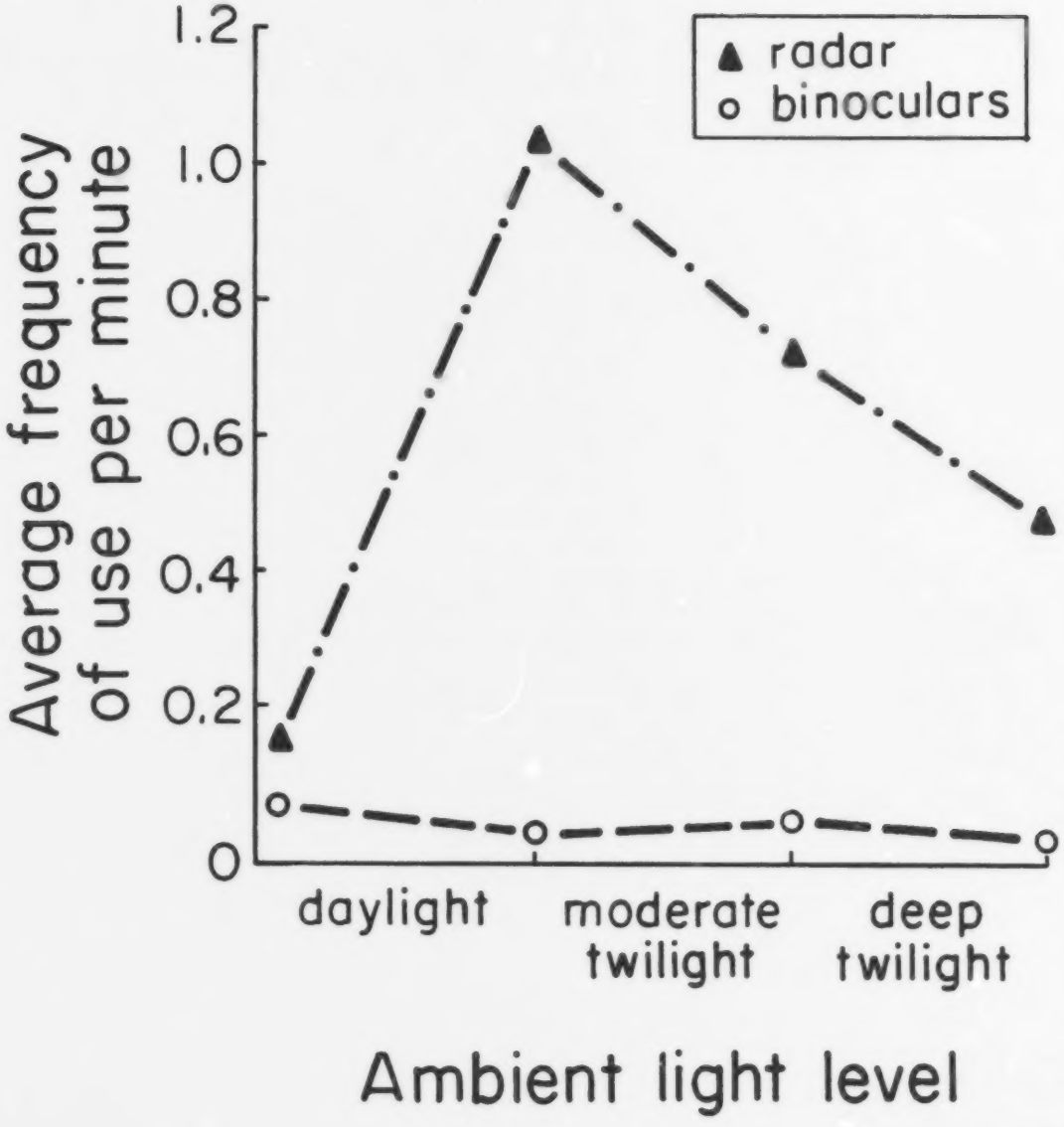

Figure 4 Average frequency of use of radar and binoculars as a function of ambient light level, M.V. Canmar Kigoriak, October 1984

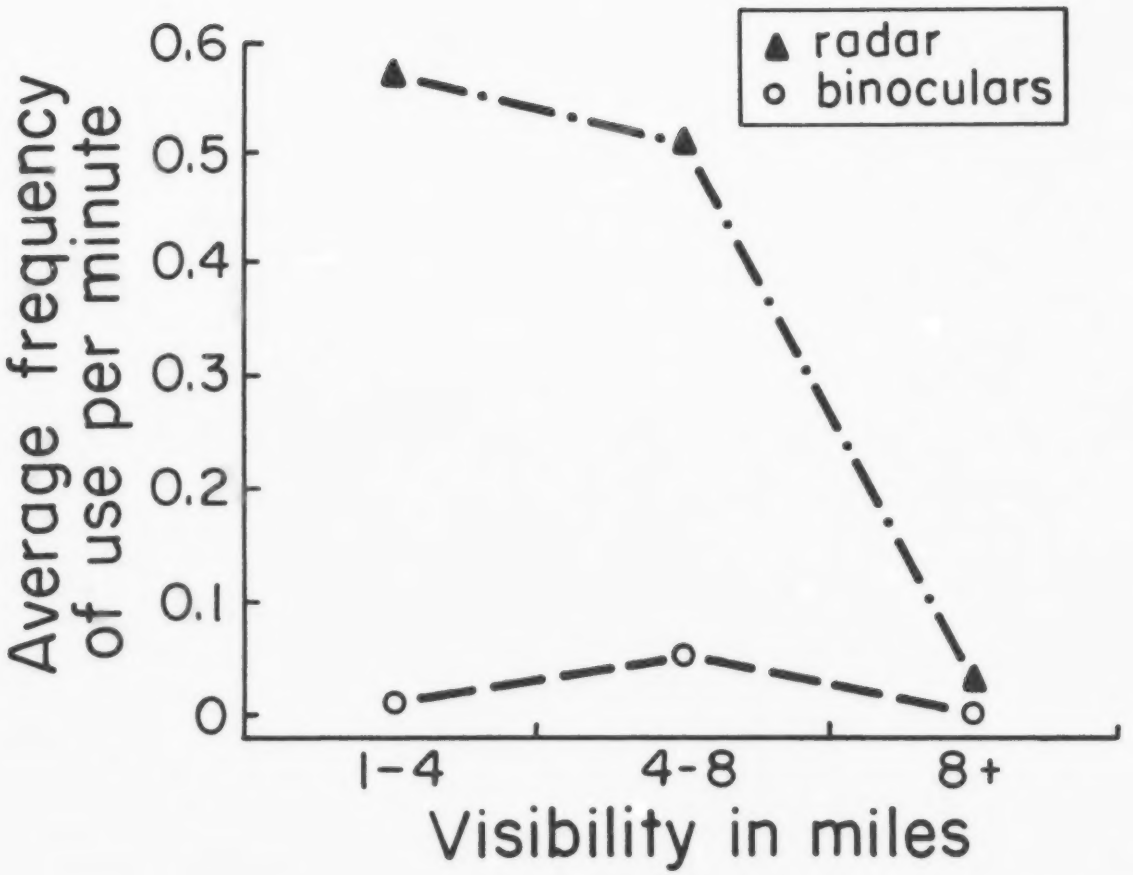

Figure 5 Average frequency of use of radar and binoculars as a function of visibility, M.V. Canmar Kigoriak, October 1984

Appendix E

NIGHT VISION IN THE ARCTIC

We have had the opportunity to observe a number of different approaches to night vision in the Arctic, aboard the M.S. Thuleland, the M.V. Canmar Kigoriak, the USCGC Polar Sea and the M.V. Arctic. In this Section we examine the use of searchlights and night vision aids. The material is presented in the context of the information needed by the operator for night vision.

The Human Visual System at Night

Vision has a feature which is like the automatic f-stop on a camera. When the general light level changes, the eye adapts to the average light level and becomes more sensitive to small brightness differences around the new level. The price paid for this ability to adjust to extreme changes in average light level is a loss of ability to see details at the light levels to which the system is not adapted.

This feature of vision is very important in planning night lighting in the Arctic. An area of bright light will enable details to be seen within the area. But, if the area is too large -- approaching one-fourth to one-third of the visual field -- the ability to see details in the darker part of the field will be severely restricted.

Floodlights versus Spotlights

There are two ways of distributing a given amount of light: floodlighting and spotlighting. In floodlighting, the light is dispersed over a wide area. In spotlighting, the light is concentrated in a narrow area. Consider an observer on a ship's bridge looking forward over the bow towards an ice sheet and the night horizon. How does his vision differ when the scene is illuminated with floodlighting or spotlighting? Assuming that the luminous source is not directly visible to the observer, all the observer sees is reflected light. The pattern of this reflected light is critically different in floodlighting and spotlighting.

A floodlight spreads a fixed amount of light over a broad area. Floodlighting thus increases the average light level of a large part of the visual field. This decreases the sensitivity of the eye to details in the areas that are not illuminated. In addition, the range of a floodlight is short. Much of what is near is brightly lit but distant objects are in the less sensitive dark areas of the visual field and so cannot be seen.

A spotlight concentrates all its light in a narrow area. Within that area, the atmosphere reflects much light, producing the spotlight beam. But when the illuminated area meets a reflecting surface at a distance, there is enough light left to reflect back to the observer, illuminating the surface.

The area of concentrated light from a spotlight is small enough that it does not bias the eye to change its average intensity setting. As a

result the visual field outside the spotlight beam remains sensitive. This means that on average, more details outside of the beam can be seen with a spotlight than with a floodlight.

Other things being equal, a spotlight is a better Arctic navigation tool than a floodlight. A moveable spotlight enables the observer to control the location of a long-range beam of light to illuminate in any available direction, and for a greater distance, than a floodlight of comparable intensity. A spotlight also does not interfere as much with vision outside of the illuminated field.

Spotlight Placement

Because it is quite bright, the beam of a spotlight obscures objects which are behind it. Spotlights should be placed so an observer is not required to look through the beam in order to see other targets. The only location which is absolutely proscribed by this condition is directly above the observer, because the beam will fall between the observer and any target which is further away than the target being illuminated. A beam below the observer's line of sight to the target does not obscure targets which are further away, neither does a beam to one side of the line of sight.

Searchlight: Current Use

The current approach to improving visibility for night navigation in the Arctic is by using high-powered Xenon-arc lamps. On the Kigoriak, there are two Xenon-arc lamps mounted on each side below the bridge deck and two mounted on the bow facing forward. Two floodlights are also mounted on the bow. On the Arctic, there are three 35 M candle power Xenon-arcs which are fixed in position and mounted on the foremast. On both of these ships the night-lighting is effective.

On the USCGC Polar Sea there are two bow-mounted and two stern-mounted flood lights as well as a Carlisle and Finch 19 inch Xenon-arc lamp that is mounted below the upper conning station and is controllable from the bridge. Carlisle and Finch Xenon-arc lamps are also installed on the M.V. Canmar Kigoriak and M.V. Arctic. The lamp on the Polar Sea is rated at greater than 90 M candle power.

On the M.S. Thuleland there are one bow-mounted and two wing-mounted Xenon arc-lamps. The bow-mounted lamp is controllable from the bridge; the wing-mounted lamps are fixed in position. The output of the lamps is rated at 12.25 M candle power each. On the Thuleland and the Polar Sea the night lighting was unsatisfactory.

During the December 1984 passage of the Polar Sea from Barrow, Alaska to Nome, Alaska, all but a small ring at the bottom of the beam was dimly lit and inadequately focused. Its effective operating range was about 300 yards. We gathered that the bulb in the arc-lamp had not been replaced for some time. Carlisle and Finch Xenon-arc lamps have performed well on other ships in the Canadian Arctic. Presumably the night lighting problem on the Polar Sea was due to an unattended bulb failure.

On the M.S. Thuleland the bow-mounted arc-lamp was used regularly. The lamp was manufactured by NOACK AS. The bulbs were supplied by OSRAM GmbH Berlin. Although the specifications for the arc-lamp were impressive -- an effective working range of 3500 metres -- the actual range achieved by the lamp was approximately 500 metres. The illumination provided by the beam was inadequate for the reliable detection of ice targets.

The most important factors in searchlight design for Arctic navigation are luminous intensity, beam focus and remote control of searchlight direction. Practical remote control requires ergonomically correct design and placement of searchlight controls. On the basis of our experience on the Kigoriak and the Arctic, we feel that multiple controllable light sources are needed to provide adequate coverage. Multiple sources also provide the possibility of illuminating the ice surface from a number of angles. Further the exterior lighting is less affected by the weakness or failure of individual bulbs when there are several lights in simultaneous operation.

Improvement of the HILS1 Vortex Arc Lamp

The HILS1 Vortex arc light source designed by MPB Technologies Ltd is a very powerful floodlight. Reports by Tam et al. (1980), Roberge (1981) and by Bayly (undated) make this clear. Bayly says (p. 1) " 1) A lot of light provided widespread illumination around the ship, but objects in the distance say over 1000 ft., were not made as readily visible as expected." and 2) "It appeared that near field brightness was interfering with vision into less well illuminated areas beyond." The baffle designed by Gentec Inc was designed to reduce the spread of light, but did not succeed in converting HILS1 from a floodlight to a spotlight. Roberge says "Les mesures effectuees au cours de ce contrat demontrent que l'intensite diffusee par les aerosols, pres de la lampe, produit un fond lumineux suffisant pour compromettre l'observation des objets eloignes."

The 60 kW marine vortex stabilized arc lamp is an impressive piece of engineering which could materially benefit Arctic marine navigation as a moveable spotlight. It should be re-designed to produce a concentrated beam which will penetrate the atmosphere and so allow illumination of visual features at a very great distance from the ship. By concentrating the beam, the atmospheric backscatter problem will be reduced, because the area over which the backscatter occurs will be circumscribed and the light can be placed to avoid illuminating masts or backstays. Its intense beam will provide useful illumination at a great range in a small package.

The way to concentrate a beam is with a lens, a reflector or a lens-reflector combination. The present HILS1 relector does not concentrate the light into a cylindrical beam. We recommend that TDC contract for the design of a lens, reflector, or lens-reflector combination which will allow the HILS1 to function as a spotlight with a very narrow beam, thus commensurately increasing its range and reducing its deleterious effects on vision outside its illumination area. This should transform the HILS1 into a successful source of illumination for Arctic navigation.

Night Vision Aids

Visual acuity is worse at night for a number of reasons. The main reason is that the spatial density of rods, the visual receptor cells in the retina of the eye that are sensitive to night illumination levels, is low. Consequently the resolving power of the visual system is reduced. Night illumination levels also increase the diameter of the pupil of the eye, which reduces both the optical quality and the depth of field.

Electronic image intensifiers act as night vision aids by increasing the overall luminance level of the visual scene. This causes the visual system to use the cone receptor cells in the retina of the eye whose spatial density and hence resolving power is high.

Conceptually, electronic image intensifiers are a worthwhile night vision aid. They both brighten and magnify the image. However, commercially available night vision aids both degrade the resolution of the visual scene and also reduce the contrast ratio between bright and dark areas of the field (see below). Reducing the contrast ratio has the effect of decreasing visual resolution. In addition, night vision aids over-stimulate the retinal rod cells and as a result the operators unaided night vision is reduced.

A luminance study was undertaken on the Thuleland using the Varo-Noctron V - model 9878 Night Vision System. Luminance levels were measured at night, both with and without the image intensifying system. The measurements were taken at deep twilight on September 6, 1984 at 00:00 local time. The luminance levels obtained are shown in Table 1.

Luminance levels are of course much higher when the scene is viewed through the night vision system. The improvement in luminance differs for the objects that were measured. The greatest absolute improvement is for the sky. The greatest relative change in luminance is for the sea.

In Table 2 luminance levels for these same objects are given for a variety of illumination conditions. It can be seen that over a wide range of luminance levels the order of luminances is: sky, ship, sea. This ordering is not altered by the use of the image intensifier.

Contrast ratios, that is, relative luminance levels, are shown in Table 3. In daylight conditions, contrast ratios between sky and sea range from 0.28 to 3.54. The ratios between ship and sea range from - 0.64 to 1.62. At deep twilight the sky / sea ratio was 1.03; this ratio was not altered by the use of the image intensifier. On the other hand, the relative luminances of ship and sea were more greatly affected. The ratio without the intensifier was 0.17; with it the ratio increased to 1.12. In effect, although the image intensifier does not alter the balance of sky and sea luminances, it has the adverse effect of increasing the brightness of the ship relative to the sea. This tends to obscure the contrast of other targets with the sea. Unfortunately no ice / sea contrasts were observed through the night vision system.

Operator Needs for Night Vision

In Appendix D we discussed human engineering aspects of ships' radar design for operations in ice. The need to reduce noise on the radar screen and to recode luminance differences between first year and old ice into colour differences was suggested.

Electronic image intensifiers have been discussed in this Appendix. Electronic image intensifiers are currently in limited use in the Arctic. The commercial models that are presently available have relatively low resolution and interfere with the operators unaided night vision. However, if high spatial resolution were available image intensifiers might be extremely useful for Arctic navigation.

We have also considered the design of exterior lighting systems for ships in Arctic waters. No systematic studies of operator performance or preference for searchlight characteristics have been conducted in the Arctic marine environment. However, our observations on ships and discussions with bridge crews indicate that the following factors are of importance to the operator for night lighting:

- luminous intensity and range of illumination
- the focus of the beam
- control of the direction of the beam
- the angle of the lighting relative to the ice surface
- the colour of the light

It is our experience that the first three factors are most critical to satisfactory night lighting.

Table 1 Increase in Luminance Using the Varo-Noctron Night Vision System, M.S. Thuleland, September 1984

	Sea	Sky	Ship
Luminance with Image Intensifier in ft.-lamberts	1.18	2.40	1.38
Luminance in ft.-lamberts without Image Intensifier	.00113	.0022	.0024

Table 2 Luminance Levels in Various Illumination Conditions, M.S. Thuleland, September 1984

Local Time	Visibility	Luminance in ft.-lamberts Sea	Sky	Ship
16:00	less than 1 mile in fog	470	600	400
21:00	less than 1/8 mile in dense fog	115	167	84
21:00	15 mi + moderate twilight	2.85	8.4	1.02
13:00	12 - 15 mi overcast	495	1380	615
15:00	15 mi + sunlight	336	1525	880

Table 3 Contrast Ratios for Different Illumination Conditions, M.S. Thuleland, September 1984

Description	Contrast Ratio	Visibility Condition
With Image Intensifier		
ship / sea	1.12	deep twilight
sky / sea	0.95	
Without Intensifier		
ship / sea	0.17	deep twilight
sky / sea	1.03	
Daylight		
ship / sea	- 0.15	less than 1 mile in fog
sky / sea	0.28	
ship / sea	- 0.27	less than 1/8 mile in dense fog
sky / sea	0.45	
ship / sea	- 0.64	15 mi + moderate twilight
sky / sea	1.95	
ship / sea	0.24	12 - 15 mi overcast
sky / sea	1.78	
ship / sea	1.62	15 mi + sunlight
sky / sea	3.54	

Note: Contrast (C) is calculated as C = (T - B) / B, where T is the target object and B is the background object. For these calculations the luminance of the sea was used for B.

Appendix F

COLOURS AND LUMINANCE IN THE ARCTIC

The colour of the ocean varies with the season, latitude, and weather. But the northern oceans have an average colour, which was measured using Munsell colour chips during a voyage aboard M.V. Arctic. The average of these measurements is presented in Figure 1, along with its Munsell colour specification. Bow and propeller washes are considerably lighter than the general ocean. The same measurement techniques were applied to bow and prop wash, and the average of these Munsell matches is also presented in Figure 1.

A Pritchard spectrophotometer was used to measure the C.I.E. coordinates of sky on two occasions: aboard the M.S. Thuleland and aboard the Kigoriak in the fall of 1984. The average of ten measurements under photopic conditions indicate that the colour of the sky remains relatively constant across a luminance range of 3 to 3500 cd/m2. As luminance declines from 3 to .03 cd/m2, both the C.I.E. x and y coordinates decrease. Average C.I.E. and Munsell values for photopic and scotopic sky are presented in Figure 2.

Although Arctic ice is nominally white in colour, there are important variations in both brightness (reflectance) and colour. Snow-covered ice of any age reflects one hundred percent of the incident light (Donderi and Ostry, 1985), and so the brightness level of this type of surface matches the brightness of the sky. On a clear day with the sun at mid-elevation (about 45 degrees), the horizon sky opposite the sun is 75 percent as bright as the zenith sky, and the ice on the horizon will be correspondingly less bright. These values were measured by direct comparison to Munsell neutral value reflectance standards.

Grease and frazil ice have the same reflectance as ocean water (54 percent, Donderi and Ostry, 1985). Gray ice has a visual reflectance, measured photometrically, of 76 percent, and so appears darker ("grayer") than old ice or first year ice. The reflectance of gray ice is illustrated in Figure 3.

Old ice and glacial ice have blue surfaces which are occasionally clearly visible. A series of these blue surfaces was measured photometrically, with results expressed in terms of Munsell standards illustrated in Figure 3.

Arctic Ocean: Munsell Colour 10 BG 3/2

Bow and prop wash: Munsell Colour 10 BG 7/4

Figure 1 Munsell Colours of the Arctic Ocean

Arctic Daytime Sky: Munsell Colour 5 B 9/2

Arctic Night Sky: Munsell Colour 10 PB 2/1

Figure 2 Munsell Colour Chips Representing Arctic Sky

Blue surfaces: Arctic old ice or glacial ice
Munsell colour 5 PB 7/6

Gray Surfaces: Arctic new (gray) ice
Munsell reflectance N 8.5

Figure 3 Colours and Reflectances of Arctic Ice

Appendix G

SHIP MOTIONS DURING ARCTIC NAVIGATION: A PRELIMINARY ANALYSIS OF DATA FROM THE KIGORIAK

The motions experienced on the bridge will vary as a function of the characteristics of the ship, the ship speed, ice conditions, and the type of ship-ice interaction (i.e. ramming versus continuous icebreaking). For simulation purposes, motion distribution data should ideally be collected for each class and type of ship in a variety of ice conditions. Ice impact (global and local loads) and acceleration data have been obtained for a number of ships. However, to the best of our knowledge, no data on the motion spectrum on the bridge have been reported.

This Appendix describes some preliminary analyses of motion data collected aboard the M.V. Canmar Kigoriak. Two aspects of the data are described - the amplitude of the ship's motions and the frequencies contained by these oscillations.

Method

The data were collected in early July, 1985 on the M.V. Canmar Kigoriak. All measurements were made during the spring breakout from McKinley Bay.

Motion Data Sample

For demonstration purposes three distinct 24-second records from among approximately 10 hours of 3-channel analog data recordings were selected. The selected records correspond to the ship at rest with engines on; heavy impact on an ice ridge; backing off the ridge after impact.

Recording Apparatus and Procedure

The acceleration data were collected on the ship's bridge by using PCB quartz accelerometers (Series 308B) and a Teac (R-61) cassette instrumentation recorder. The accelerometers allow the transduction of motion in the standard three translational axes of ship motion: surge, heave, and sway. However, note that the three axes of motion measured in the present data are not simply measures of translation alone. Since motion was measured from a position on the bridge, rather than the centre of gravity of the ship, the output from each measurement transducer contains contributions from the motion in one translational and two rotational axes. These are the motions which the operator on the bridge experiences and thus motions which must be quantified for simulation.

Digitization Procedure

The signals from each of the three analog channels were amplified and low-passed filtered with a cutoff frequency of 110 Hz, then digitally sampled at a rate of 250 Hz to 12 bits of resolution. This digital signal was then transformed to units of g/1000 (.0098 metres/sec/sec) on the basis of accelerometer calibration data and constant voltage test signals recorded at the time of data acquisition.

Power Spectra

Power spectra of bridge motion were computed using the segment averaging method (Beauchamp & Yeun, 1979). Each 24-second record was divided into 8 overlapping segments of 2048 samples each with the segments spaced 2 seconds apart. A fast Fourier transform was performed with a frequency resolution of .24 Hz. The squared magnitudes of the transforms were than averaged over all 8 segments and smoothed with the Hanning spectral window. We found this frequency-domain windowing procedure produced better results on visual inspection than multiplying a window directly into the data in the time domain.

Acceleration Relative Frequency Distribution

For each record, the range of accelerations observed was divided into 25 equal-width bins. The number of samples was counted. Dividing this count by the total number of samples in the record produced a relative frequency distribution for accelerations. The choice of 25 bins was arrived at empirically to produce a smooth distribution function.

Velocity and Displacement Records

Numerical integration according to Simpson's rule was used to compute both velocity and displacement measures. Velocity, calculated by numerical integration of acceleration, is computable only to a constant. We have estimated this constant by subtracting the mean of the data from each sample. This computed velocity information was similarly integrated and the mean subtracted to compute displacement. No velocity or displacement estimates were computed for the surge dimension of the moving ship because, in this case, the assumption of zero mean velocity is clearly false.

Results

Amplitude Measures

From a simulation viewpoint it is important to know the range of the amplitudes of ship movements and their derivatives. Figures 1, 2 and 3 show typical records of surge, heave and sway accelerations, velocities and displacements for the ship stopped with engines running, the ship ramming a ridge in first year landfast ice and the ship backing from this ridge. Figure 4 shows shows portions of the acceleration recordings for each of the three measurement axes for the same three events. Note that the scales are different in the various plots.

The energy in the ships oscillations is differentially distributed in the different axes of motion. For example, in backing from the ridge, the heave axis exhibits a much greater overall maximum acceleration, whereas in ramming the ridge, the sway acceleration is large.

In Figures 5, 6, and 7, the magnitude distributions of acceleration are displayed for each measurement axis. In this case the distribution was constructed as a percent of time spent in any region of the acceleration sample space. Thus the distributions are more or less symmetric around the zero acceleration point. It is clear from these plots

that the bulk of the energy is in the low amplitude acceleration range and the distribution is roughly Gaussian. Only a small percentage of the accelerations exceeded .05 g in any of the measurement axes. Similer ranges of acceleration were observed by Noble, Tam, Menon & Bayly (1979).

The largest absolute accelerations observed were the large accelerations in the surge axis during ramming. These correspond to the rapid deceleration of the ship upon heavy impact with the ridge. Large sustained accelerations in the surge axis are more difficult to simulate than vertical and rotational accelerations. This is due to the movement limitations of a simulator motion platform. The large surge acceleration component in ramming may be difficult to simulate realistically.

Frequency Analysis

In Figures 8, 9, and 10, power density functions for the acceleration data for each measurement axis are displayed for three sampled events. The energy concentrations differ somewhat for the three measurement axes and events. In all cases, however, the bulk of the energy is contained within the 5 - 20 Hz range. The spectra for the ship stopped with engines on show the characteristic low amplitude broad-band features of vibration. Spectra for ramming and backing show the high amplitude, narrow-band motion usually seen when ships are in open water.

When the ship is stopped with engines running, the spectral peaks reflect resonances due to shaft and engine velocities. These low amplitude vibrations are a significant part of the motion environment of the bridge and could be simulated independent of a full motion generator. This could contribute significantly to realism without the full expense of a large-scale motion platform.

During continuous icebreaking, these static spectral representations may provide a sufficient description of the motion environment. However, when an event such as ramming or backing occurs, it is important to examine the changes in the spectrum over time. Figure 11 displays the power density function for the surge, heave and sway axes on ramming a ridge, with time displayed on the Z axis. The relative amplitudes of the frequency peaks shift over the course of the sample. For example, the large 9.6 Hz peak visible in the average power density function for the surge axis (Figure 11a) changes in amplitude as a function of time.

Summary

Two of the most important characteristics of motion generation systems are the excursion limits and the dynamic threshold. The former refers to the operational limits of displacement, velocity and acceleration during simulation. The latter refers to the response time of the system in providing a given motion cue. While low dynamic thresholds are less important in maritime simulation than in the simulation of high speed aviation manoeuvres, the requirements of Arctic shiphandling simulators can only be assessed for both of these characteristics through detailed analysis of ice trials. This Appendix has provided a preliminary analysis of this kind of data. The small sample analyzed makes detailed discussion of the quantitative results inappropriate.

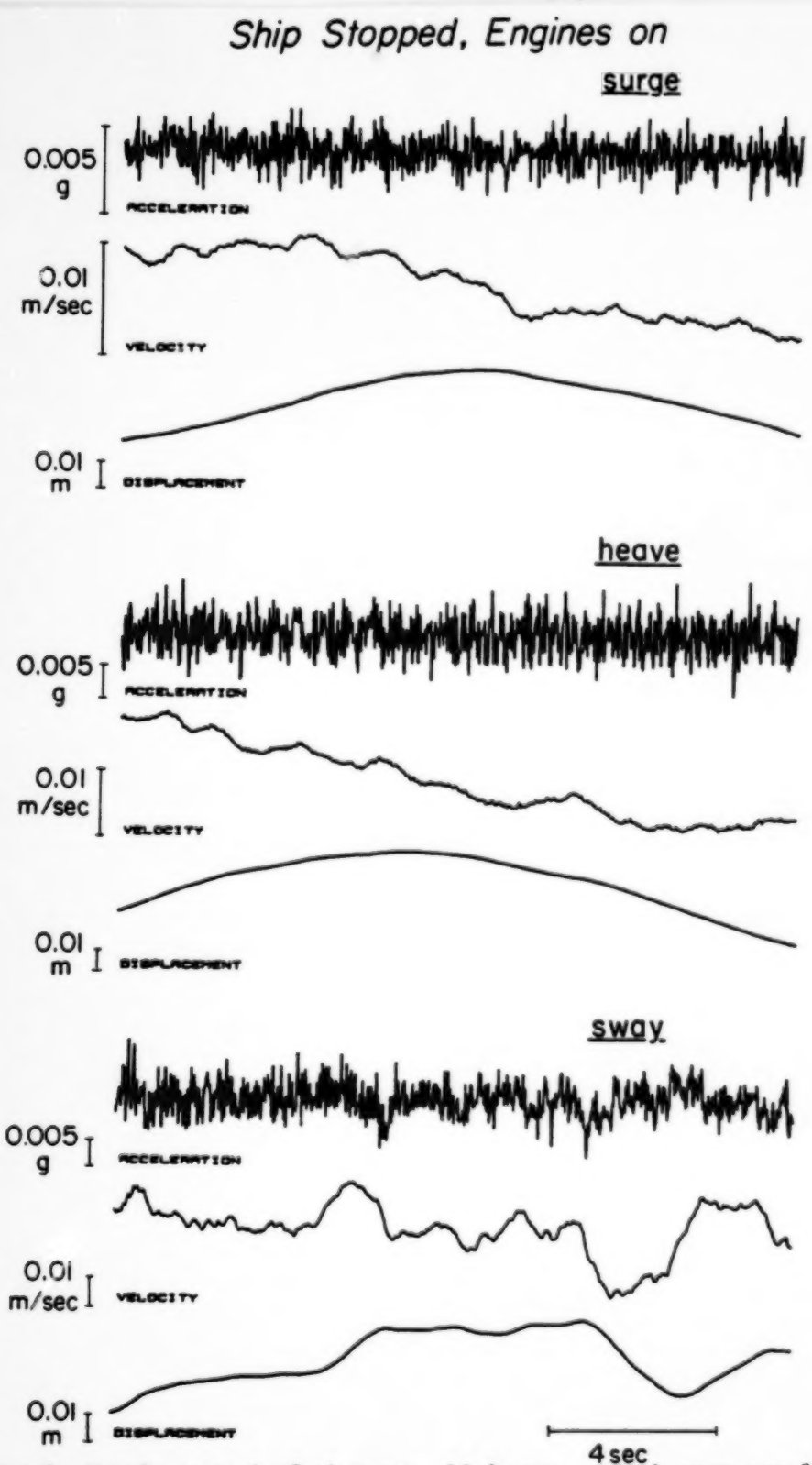

Figure 1 Sample record of a) surge, b) heave, and c) sway acceleration, velocity and displacement records, ship stopped engines on.

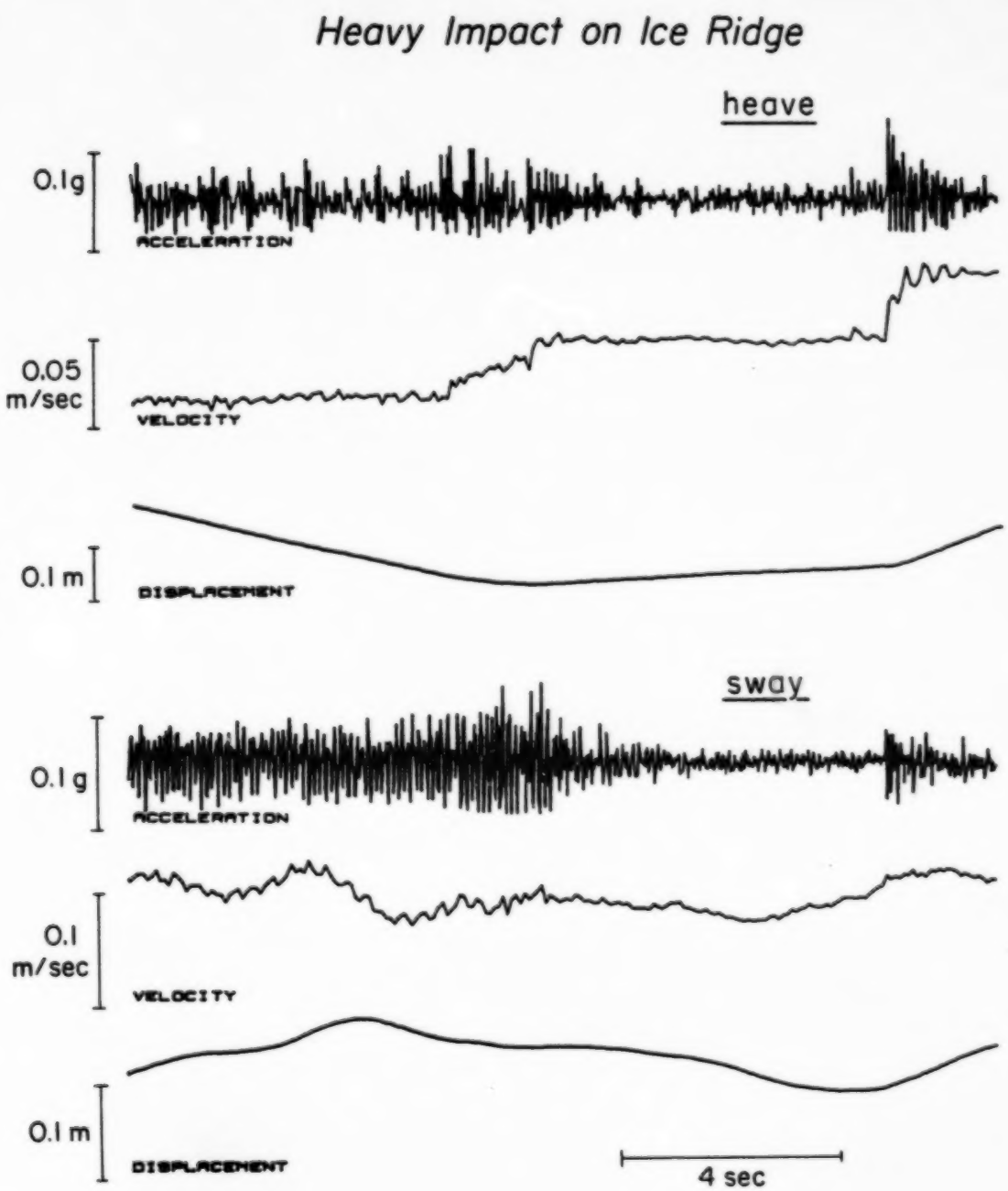

Figure 2 Sample record of a) heave and b) sway acceleration, velocity and displacement records, heavy impact on ice ridge

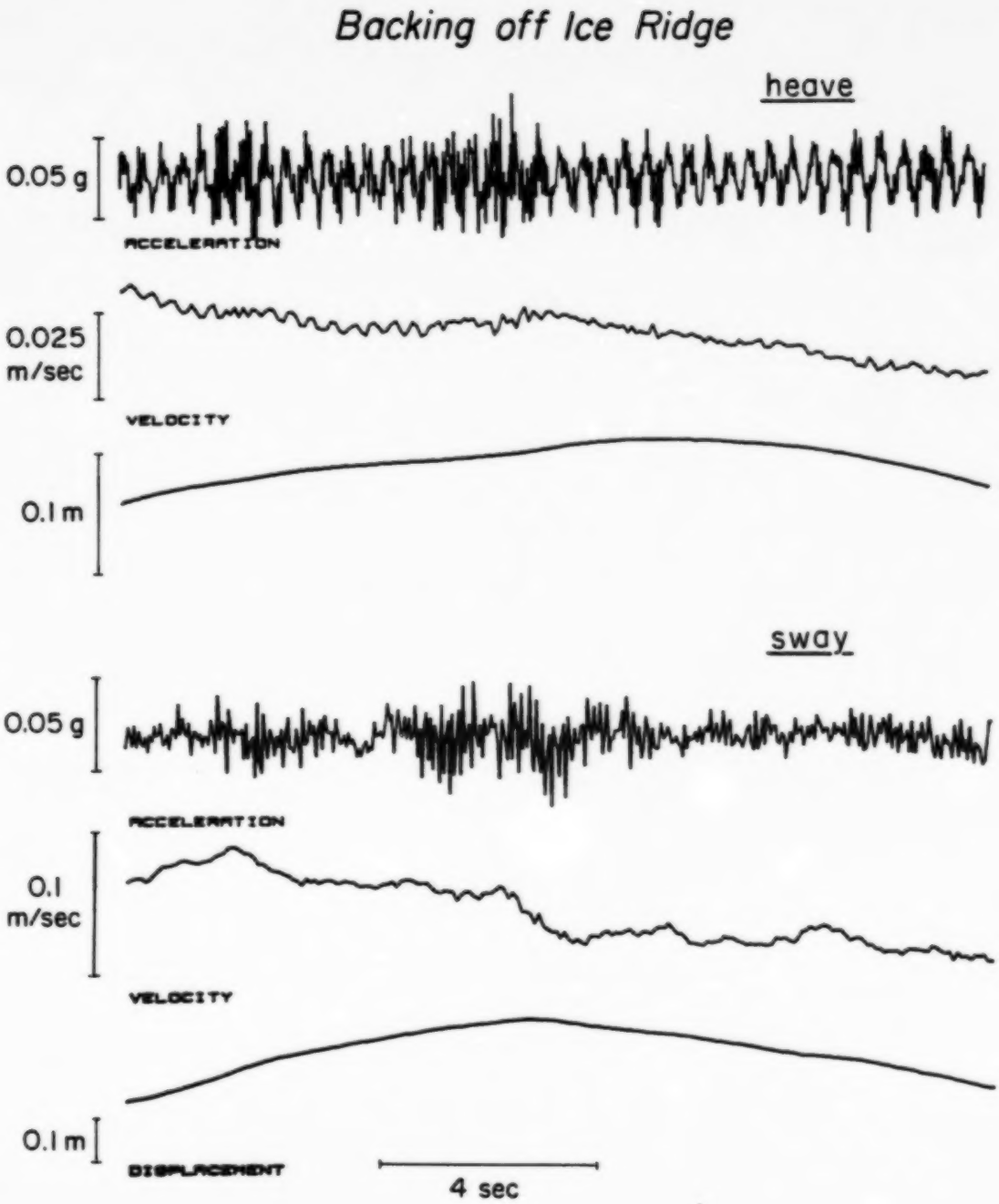

Figure 3 Sample record of a) heave and b) sway acceleration, velocity and displacement records, backing off ice ridge

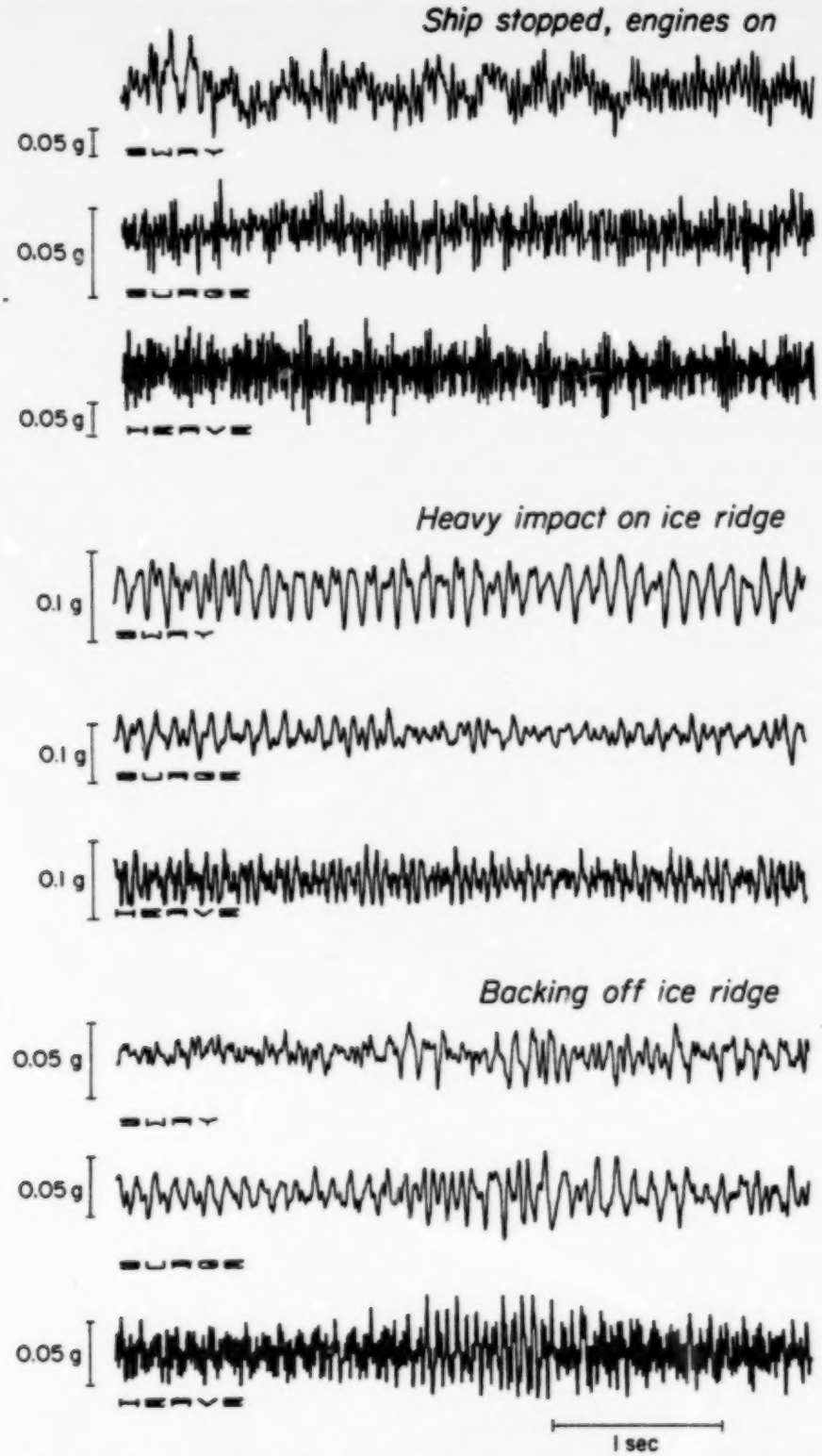

Figure 4 Sample acceleration records of a) surge, b) heave, and c) sway for ship stopped with engines on, heavy impact on ice ridge and backing off ice ridge

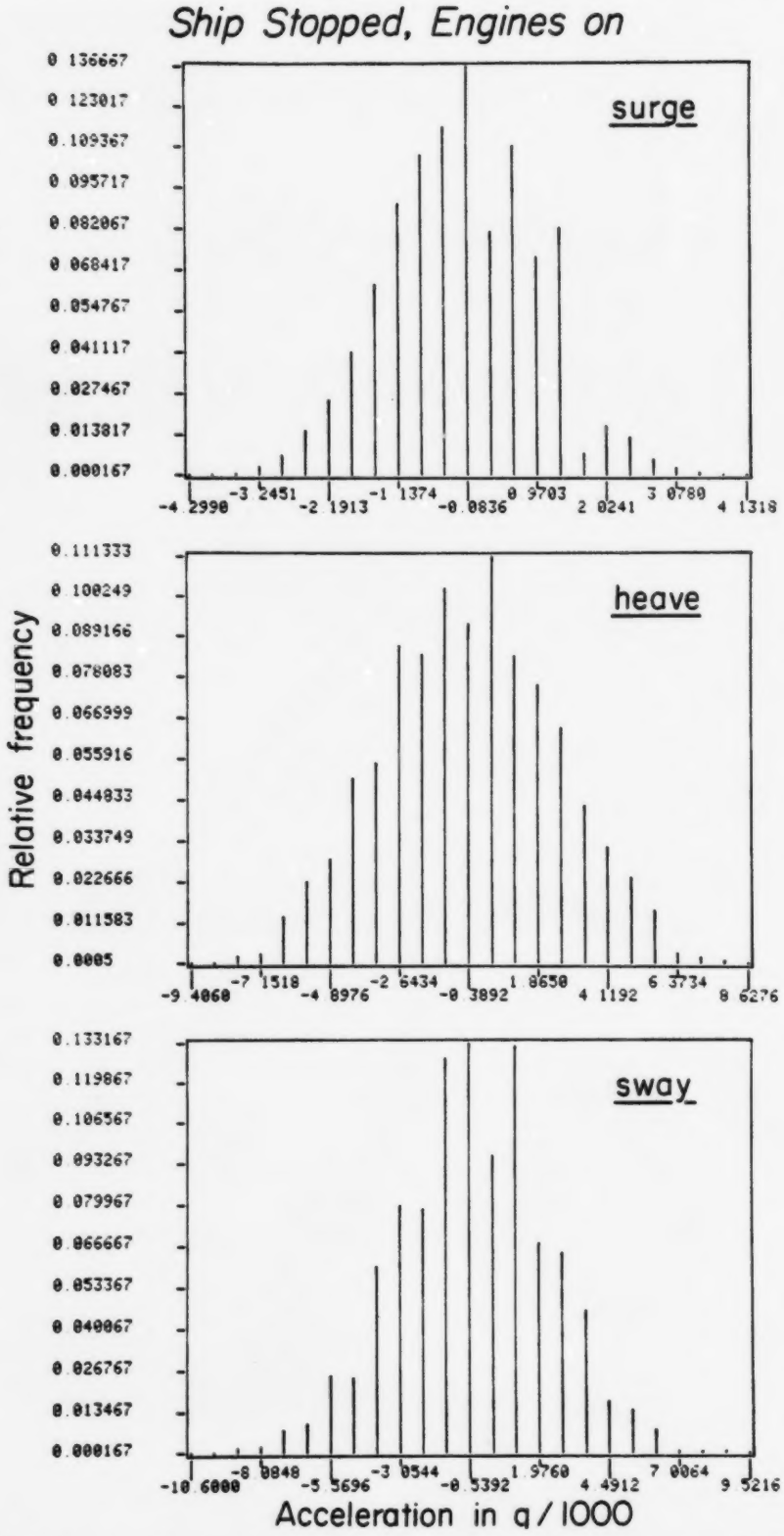

Figure 5 Relative frequency distributions of the magnitude of a) surge, b) heave, and c) sway accelerations, ship stopped with engines on

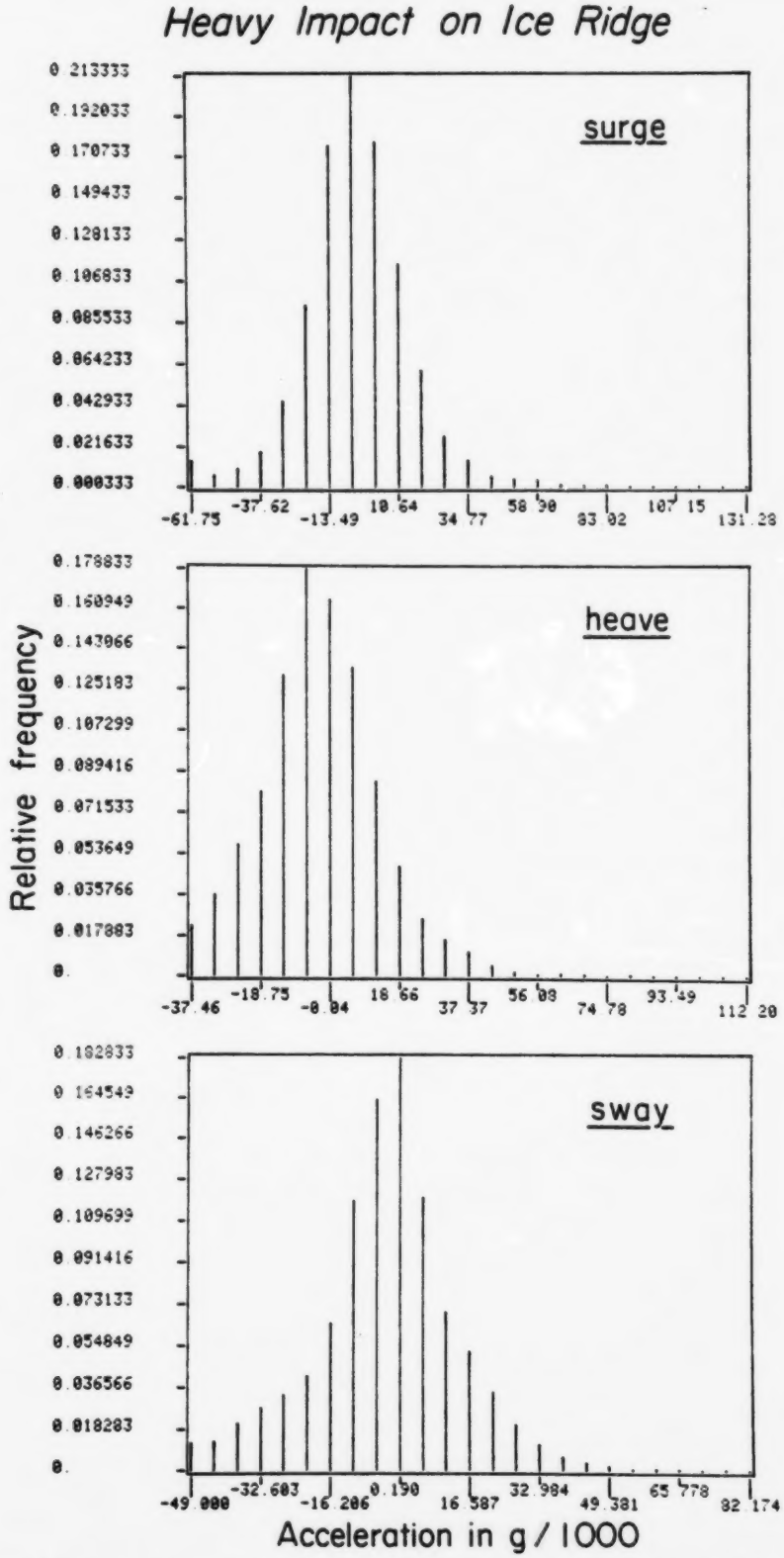

Figure 6 Relative frequency distributions of the magnitude of a) surge, b) heave, and c) sway accelerations, heavy impact on ice ridge

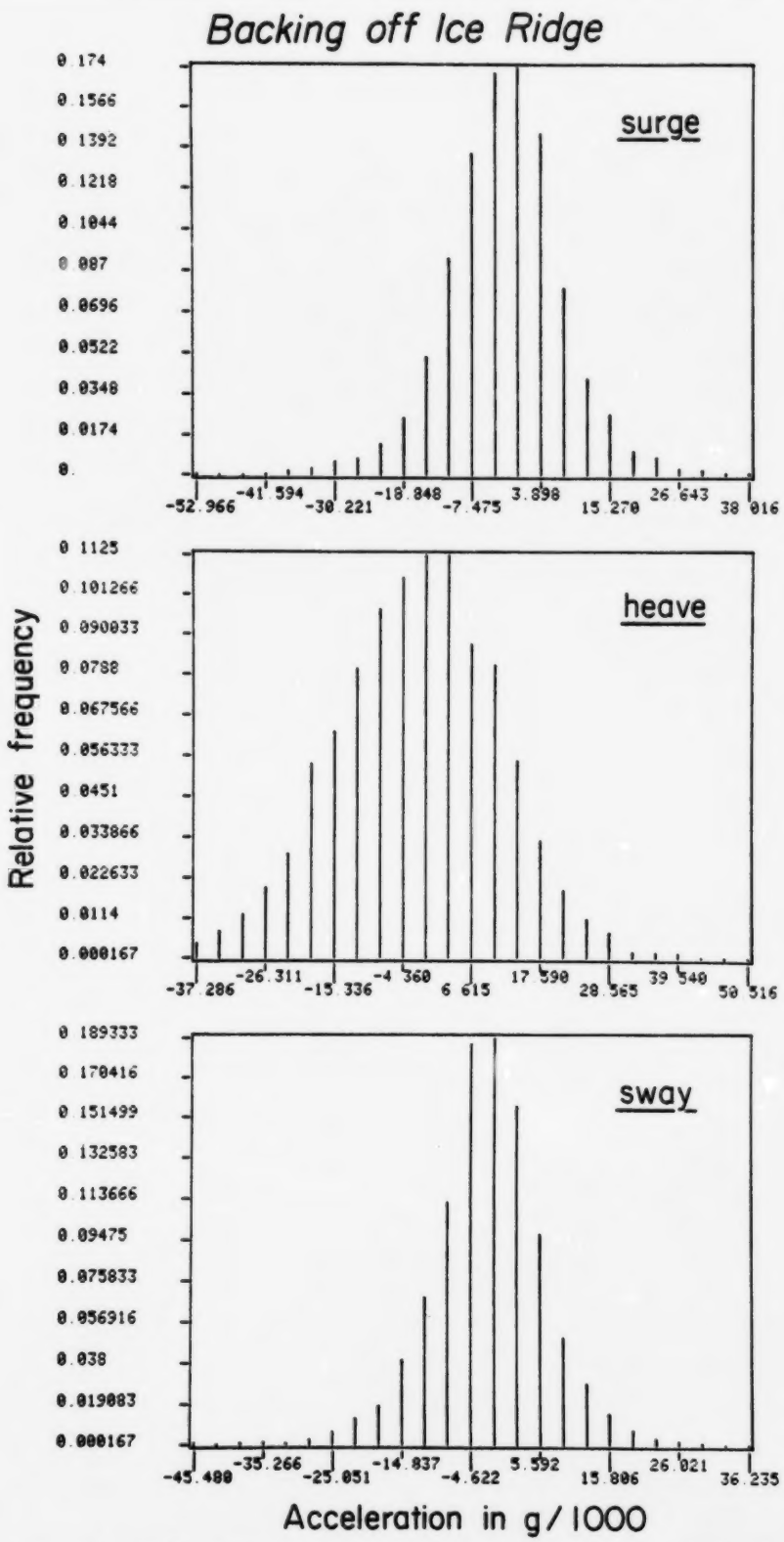

Figure 7 Relative frequency distributions of the magnitude of a) surge, b) heave, and c) sway accelerations, backing off ice ridge

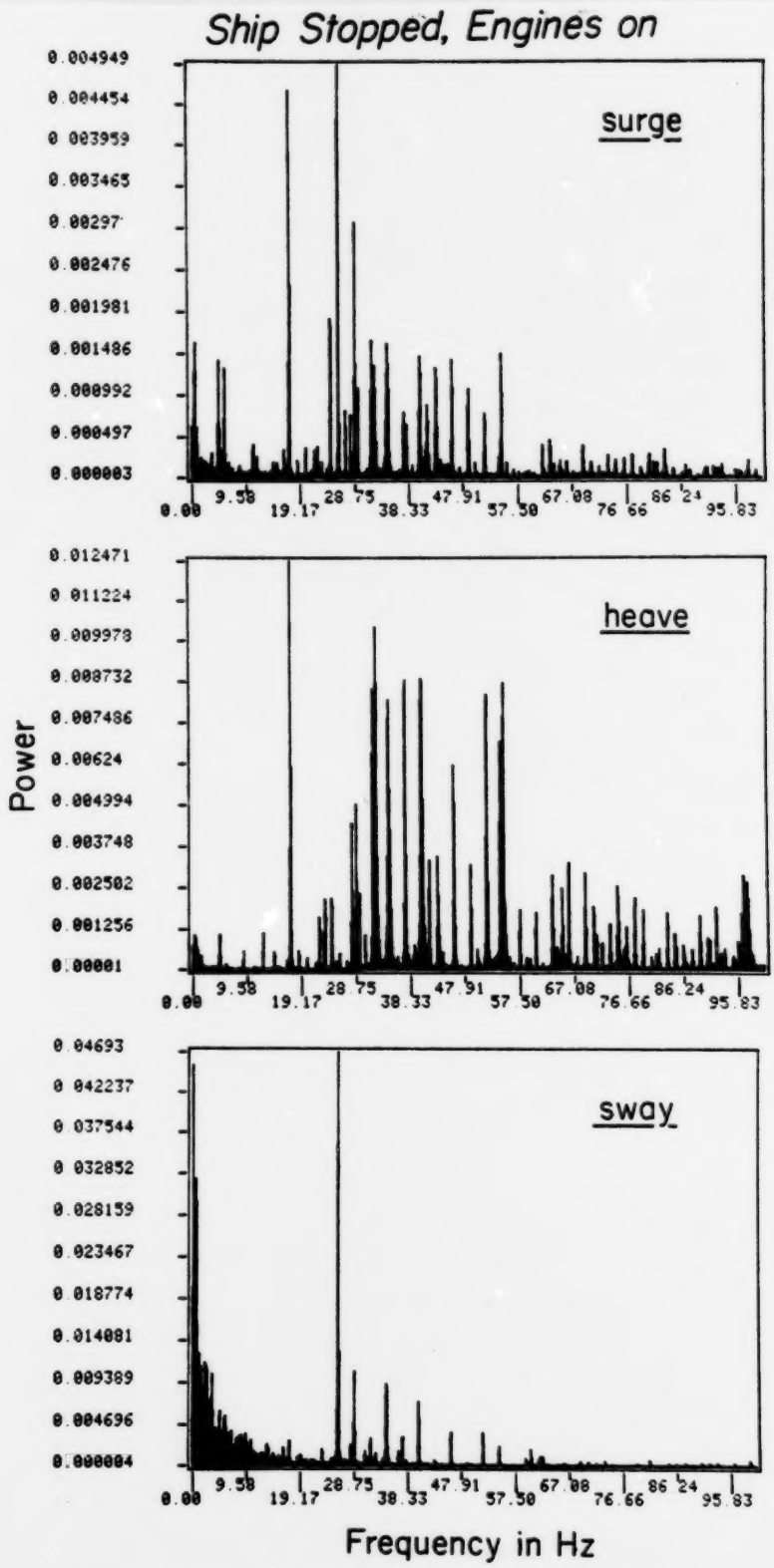

Figure 8 Power density functions of frequency components for a) surge, b) heave and c) sway accelerations, ship stopped, engines on

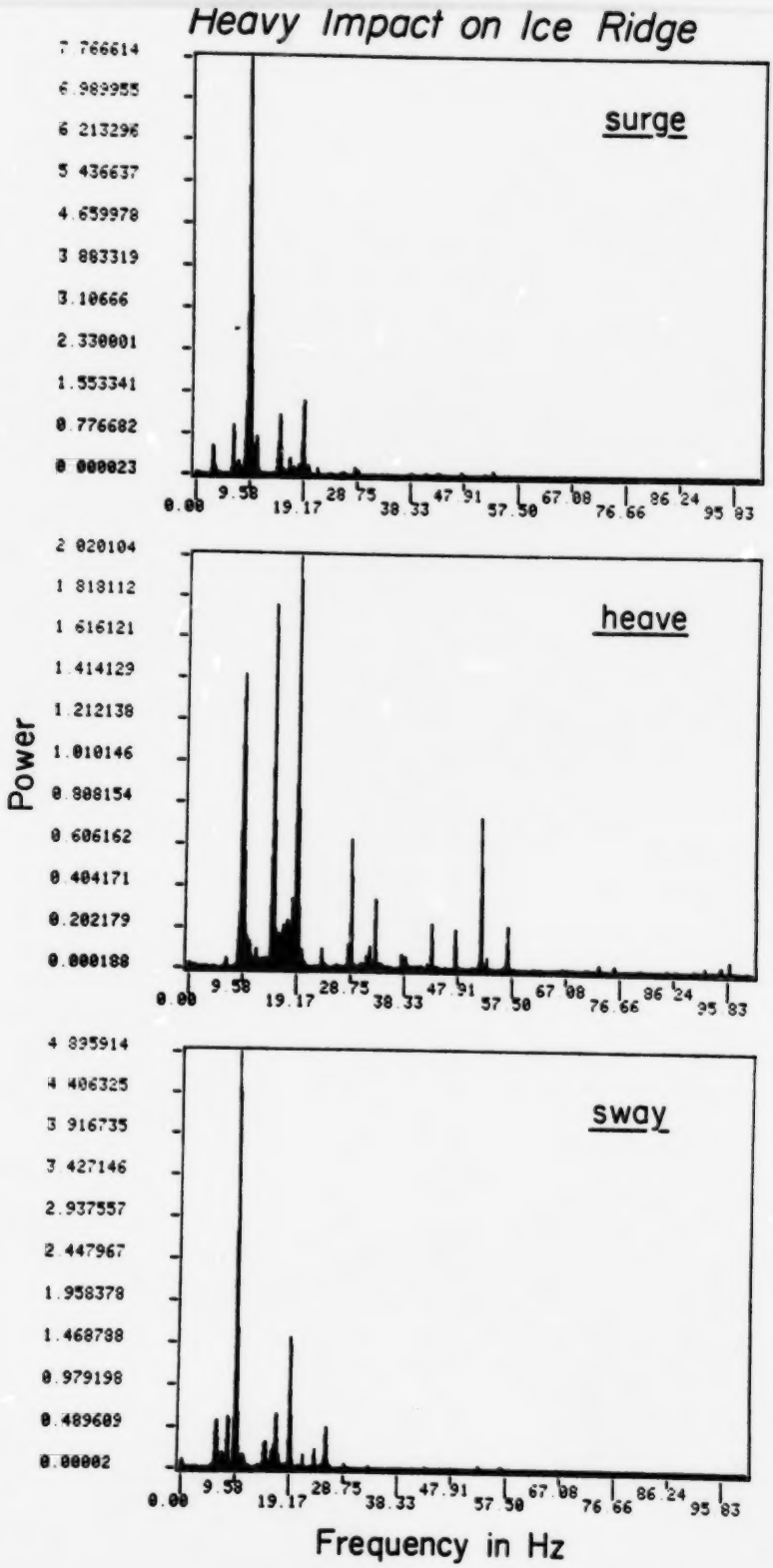

Figure 9 Power density functions of frequency components for a) surge, b) heave and c) sway accelerations, heavy impact on ice ridge

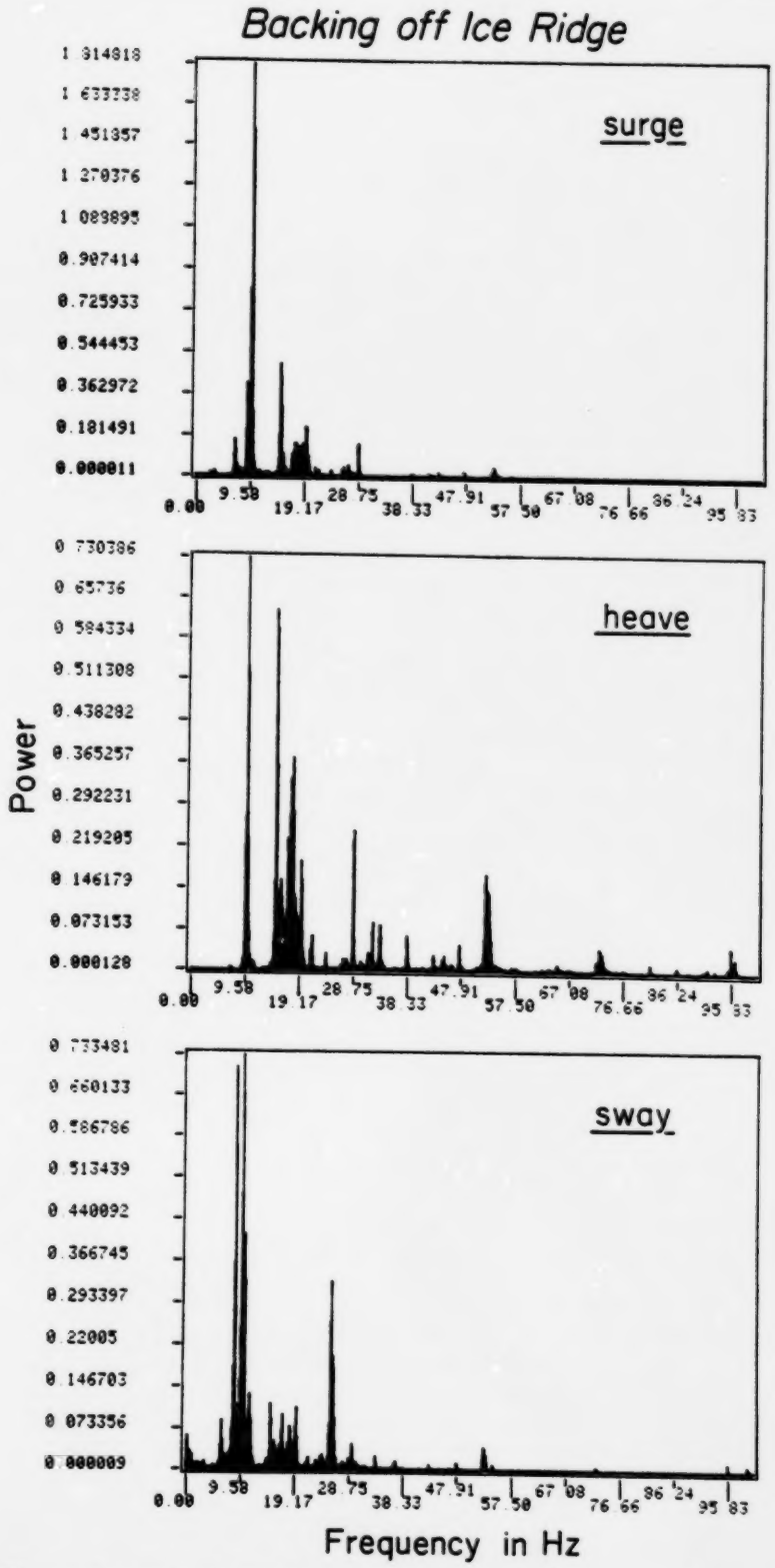

Figure 10 Power density functions of frequency components for a) surge, b) heave and c) sway accelerations, backing off ice ridge

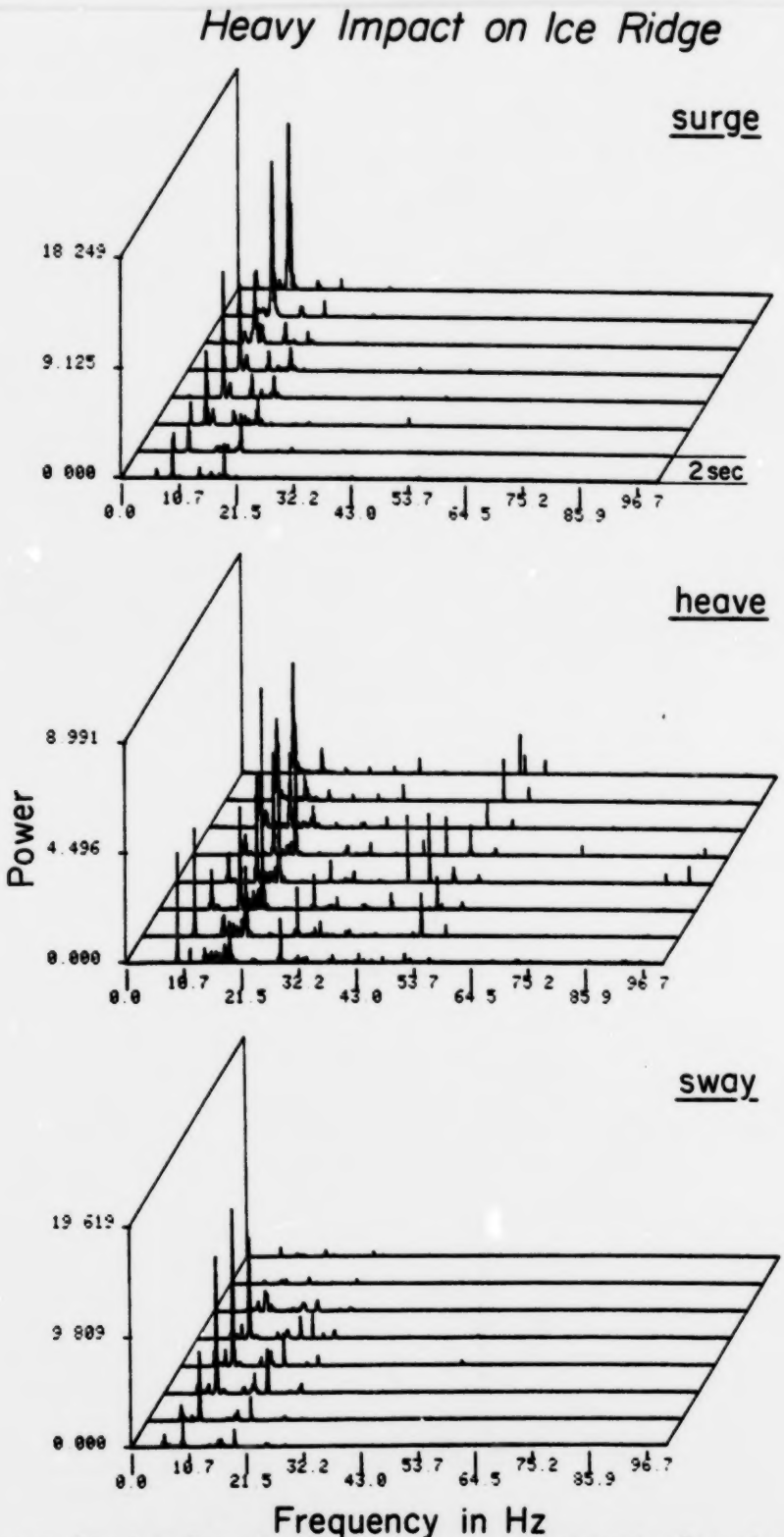

Figure 11 Power density functions of frequency components for a) surge, b) heave and c) sway accelerations during ramming as a function of time

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